EFFECT OF PROCESSING CONDITIONS ON PHYSICAL, CHEMICAL, COOKING, AND SENSORY PROPERTIES OF *OFADA* RICE*(Oryza sativa L)* GRAIN AND FLAKES

BY

ADEKOYENI OLUDARE OLUMUYIWA

BSc.Food Science and Technology (FUNAAB),MSc. Food Technology (Ibadan)

(MNIFST)

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ABSTRACT

Rice is a staple food in Nigeria with consumer preference for imported varieties due to good quality. *Ofada* rice (OS6) is a local variety characterised with unpleasant smell and unappealing appearance. Previous researches to improve *Ofada* rice quality have not satisfactorily solved the problem. This study was designed to determine effect of processing conditions on physical, chemical, cooking and sensory properties of *Ofada* rice and flakes.

Trial experiments were done to determine variables and responses of experimental design. The variables (storage, soaking, parboiling and drying) were interacted using response surface methodology and responses (physical, chemical, cooking, and pasting properties) for each experimental combination were analyses. Physical (length, width, breadth, head rice yield, brokenness, chalkiness and colour) properties of the samples were determined using ASABE methods. Chemical (protein, fat, ash, carbohydrate, metabolisable energy, free fatty acids, and amylase, zinc, iron, magnesium, copper, potassium and calcium) properties were determined using AOAC methods. Methods of AACC were used for determination of cooking (cooking time, water uptake ratio, solid loss and elongation) and pasting properties. Ready-to-eat rice flakes were produced by pressing and roasting pressure-cooked rice dough. Proprietary software was used to model and optimise process parameters for both grain and flakes. Predicted optimum conditions for rice grain and flakes processing were validated using experimental values. Adsorption isotherm of flake was determined at 25, 35 and 45 ^{o}C for 14 days using gravimetric method. Sensory characteristics of cooked rice and flake produced at optimised condition were determined using panelists.Data were analysed using regression and ANOVA at p=0.05.

The ranges of length, width, breadth, head rice yield, brokenness, chalkiness and colour lightness of the rice grain were 5.5-6.3 mm, 2.5-3.0 mm, 1.9-2.4 mm, 50.7-76.5 %, 0.8-83.1 %, 0-49.6 %, and 66.0-78.8 respectively. The rice contained protein (8.4-10.4%), fat (0.7-3.8%), ash (0.1-1.0%), carbohydrate (78.6-84.4 %), metabolisable energy (390.3-395.2 kcal/100g), free fatty acid(1.2-4.8%) and amylase (18.5-26.5 %). Storage, soaking, parboiling and drying temperature significantly influenced cooking properties of rice grain. Iron (24.0-75.0 mg/kg), zinc (13.0-42.5 mg/kg) and magnesium (234.3-366.2 mg/kg) were the major minerals found in the rice grain. Drying temperature and storage duration significantly influenced pasting properties of the grain. Coefficient of determination (R^2) of predicted models ranged from 0.1 to 0.8. The best rice grain was obtained at grain storage for eight months and 19 days, soaked for one day and 20 h, parboiled at 113.0 °C, and dried at 43.2 °C while most acceptable flakes were obtained at grain storage of nine months, soaked for four days and 17 h, parboiled at 106 °C and dried at 30 °C. Deviation between experimental and predicted values ranged between 0.9 and 0.93 % for rice grain and flakes. Adsorption isotherms of the flakes best fitted into Guggenheim Anderson De Boer model (R^2=0.96). Flavour and appearance of the rice and flake produced at optimised condition were acceptable to panelists.

Appropriate storage duration and processing conditions have been established and found to successfully eliminate unpleasant odour and improved appearance of *Ofada* rice grain. Ofada rice was found suitable for production of ready-to-eat flakes which is an alternative means of harnessing potential of *Ofada* rice.

Keywords: *Ofada* rice, OS6 processing conditions, Sensory characteristics, Rice flakes

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CERTIFICATION

I certify that this work was carried out by Adekoyeni Oludare Olumuyiwa in the Department of Food Technology, University of Ibadan.

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Supervisor

Dr. Rahman Akinoso

B.Sc., M.Sc., Ph.D. (Ibadan)

MNSE, MNIAE, MASABE, MNIFST, R. Engr (COREN)

Department of Food Technology, University of Ibadan, Nigeria.

DEDICATION

This work is dedicated to the ever memory of my loving father Pa Johnson Folorunso Adekoyeni

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LIST OF ABBREVIATIONS

Symbol/Abbreviation	Meaning	Unit
AACC	Analytical Association of Cereal Chemists	
AOAC	Association of Official Analytical Chemists	
ARI	American Rice Incorporation	
ASABE	American Society of Agricultural and Biological Engineers	
BET	Brunauer Emmett and Teller	
CHO	Carbohydrates	%
DOM	Degree of Milling	
E	Percentage Deviation	%
EMC	Equilibrium Moisture Content	
EME	Emerging market Economy	
FAO	Food and Agricultural Organisation of United Nations	
FFA	Free Fatty Acids	%
GAB	Guggenheim Anderson De-Boer	
HRY	Head Rice Yield	%
IDP	International Development Programme	
L	Length	mm
LPL	Lysophospholipid	
L/W	Length/Width	Unit less
ME	Metabolisable Energy	kcal/kg
NCRI	National Cereal Research Institute	
NERICA	New Rice for Africa	
r.p.m	revolution per minute	

SPSS	Statistical Package for Social Sciences
TGW	Thousand Grain Weight g
USAID	United States Agency for international Development
USARF	United States of America Rice Federation
WARDA	African Rice Center (formerly West African Rice Development Association)
WHO	World Health Organisation

CHAPTER ONE

INTRODUCTION

1.1 Background information

Rice (*Oryza spp*) is the second leading cereal after wheat and staple food of half of the World's population (Abbas *et al., 2011*). It is grown in at least 114 countries with global production of 645 million tonnes (IRRI, 2008). It is one of the most important crops in Nigeria and its production represents a significant part of the government strategy to overcome food shortage and improve self-sufficiency for both local consumption and export. The growing importance of rice in the diet of Nigerians is evidenced by the importation of processed rice despite increase in local production (Enwerem and Ohajianya, 2013; NCRI and WARDA, 2007; Adeyemi *et al.*,1985).

Nigeria is the highest importer of rice in Africa, and the second highest in the World (Sowunmi *et al.*, 2014). Nigeria is West Africa's largest producer of rice, producing an average of 3.2 million tons of paddy rice (~ 2million tons of milled rice) for the past 7-years (Enwerem and Ohajiaya, 2013; Daramola, 2005). Domestic supply has not kept pace withdemand as imports have steadily increased faster than domestic supply by accounting forclose to 60% of total supply. However, consumer preference for imported rice is high because of its quality compare to local rice.

Rice, although a later food in average Nigerian diet, has now become an important staple to such extent that the annual per capita of milled rice stands at 25kg per person (NCRI and WARDA, 2007). A combination of factors seems to trigger the increase; according to Nwanze *et al.*, (2006) and Akanji, (1995), this was attributedto population growth and consumer preference associated with opportunity cost of their time and cooking convenience of rice. Rice is now a daily item on Nigerian's menu unlike in the past when Nigerian consumed rice only during ceremonies or festivals such as Christmas, Easter, Idel-filtri and Idel-Kabir, today rice is hawked on the street of cities and villages.

Nutritionally, it is a wholesome cereal grain that is ideal for diverse nutritional needs. It contains predominantly carbohydrate, low in fat and the protein content is comparable to that of wheat, corn and sorghum (URF, 2002). Digestibility is high compared to other cereals and provides an excellent source of vitamin E, B (thiamine, Niacin) and potassium (Ngoddy and Ihekoronye, 1985). Rice accounts for about 60-70 % of total food intake and about 90-95 % Nigerians consume rice and this cut across all economic class where it is eaten in different recipes (Wudiri, 1992). It is a traditional food plant in Africa, with the potential to improve nutrition, boost food security, foster rural development and sustainable landrace (NRC, 1996). More demand for rice may also be as a result of its ability to cope with disorders like diabetes (Bandara *et al.*, 2007).

There are two cultivated species of rice, the *Oryza glaberrima Steud* and the *Oryza sativa* L. The*Oryza glaberrima* known as West African wild rice were cultivated in most part of Nigeria, namely Abakaliki, Bida, Abeokuta, Markudi, Mokwa, Sokoto, Nasarawa, and Benue trough where it was mainly for human consumption (Adebowale *et al.*, 2010). With the introduction of *O. sativa* from Asia, the indigenous rice species *O. glaberrima Steud* was pushed to the marginal areas. Rice cultivation is widespread within the country extending from the northern to southern zones with most rice grown in the eastern (Enugu, Cross River and Ebonyi States) and middle belt (Benue, Kaduna, Niger and Taraba States) of the country (Daramola, 2005).

Observations have shown that there is preference for imported rice rather than for locally processed rice with the former possessing better processing and cooking qualities (Adeyemi *et al.*, 1985). The non competitiveness of Nigerian rice with imported rice is majorly as a result of obsolete and inefficient processing technology (especially parboiling) which lead to smelling and unappealing products, presence of stones, uneven grainsand non uniformity in the quality characteristics of same variety of locally processed rice due to variation in processing operations (Daramola, 2005). WARDA, (2003) reported that although imported rice is on average 30% more expensive than local rice, consumers preference for imported rice is high because it is cleaner and has a better appearance.

One of the popular indigenous rice varieties in Nigeria is *Ofada* rice. The original *Ofada* rice is short grain robust rice believedto be OS6 and ITA 150 varieties.They are named after Ofada, a small rural community in Obafemi Owode Local Government Area of Ogun State (NCRI and WARDA, 2007). It is unpolished short grain with red kernels which researchers say is not related to any other rice known in Nigeria. *Ofada* rice could be likened to the popular "basmatic rice" from India and Pakistan. The rice is processed traditionally by parboiling method that involves three stages of treatment (soaking, parboiling and drying).This rice is specially relished because of its characteristics flavour that develops during soaking as a result of fermentation activities of some microorganisms (Adeniran *et al.*, 2012).

The aromatic nature of *Ofada* rice is offensive to many people which may be as a result of processing conditions; fermentation due to several days of soaking (7 days) and production of oxidation products caused by degradation of fatty acid content of the rice during storage and processing. Presence of inherent enzymes especially lipase also result in splitting of triglyceridecomponents of rice into free fatty acids and produces objectionable odour *(Ramezanzadeh et al., 2000).*It is recognised that quality of parboiling and drying operations have a great influence on the technical performance of milling and hence the quality of rice. Poor condition of paddy storage and ageing also affect the quality of milled rice.

Generally, parboiled rice produced from rough rice leads to increase yellowness, undesirable smell during soaking and retarded heat transfer to the kernel because the siliceous husk does not wet easily and resists water movement into the kernel (Bhattacharya and Subba rao, 1996). There is also problem of uniformity in the variety of rice cultivated and processing hence, the frequency of broken and uneven grains. Other factors like soil, environment, cultural and agronomic practices have also been mentioned to have effects on the grain quality characteristics. Most of the highlighted defects can be upgraded through proper unit operation monitoring and control in term of process optimisation.

A lot of research has been carried out on various aspects of rice processing technology to improve quality and sensory characteristics but this study focussed on local cultivar “*Ofada*-OS6’’ to explore its potential. One of the major insight of this research work is to investigate the effect of the processing unit operations involved; soaking time, parboiling temperature, drying temperature and storage duration to provide a very rough guide to positioning the optimum processing conditions in terms of factors varied towards production of quality grain of enhanced organoleptic taste and improved characteristics for various end uses of local rice. Optimisation is an act of making the best combination of elements or variables selected to synthesis a system in order to yield the best result. Optimum conditions are those that produce the best, most favourable or most beneficial result from a system or process (Olaoye and Oyewole, 2012).

Response surface methodology (RSM) is important in designing experiment, formulating, developing and analysing new and existing scientific studies cutting the cost, and measures several effects by objective test (Akinoso and Adeyanju, 2010; Montogomety, 2005). The method of response surface deals with the problem of seeking the conditions which are optimum. Therefore, the application of response surface is a veritable tool at determining various optimum processing conditions of local rice for various end uses. Presently, there is little or no information on the use of response surface methodology in optimum determination of processing condition of local rice in Nigeria.

However, rice produced in Nigeria is consumed mostly in form of boiled rice and as mashed porridge rolled into round balls both eaten with soup. There is little or no utilisation of rice flour in Nigeria in pastry production, however, production of breakfast cereals from maize, sorghum, millet is common, and the production method varies with locality. The use of rice for preparation of breakfast cereal such as noodles, flakes is common in United States and Europe. Efforts are therefore required to utilise Nigeria local rice for production of ready-to-eat flakes as another way of harnessing the potential of local rice.

1.2 Objectives

The main objective of the research work is to optimise processing conditions of milled rice and flake from *Ofada* paddy.

The specific objectives of the study are to:

1. determine the effect of soaking time, parboiling temperature, drying temperature and storage duration of paddy on physical, chemical, cooking, pasting and sensory properties of milled*Ofada* rice.
2. evaluate the quality of ready-to-eat flakes produced from *Ofada* rice.
3. derive suitable conditions for processing of paddy rice and flakes through optimisation in order to capture current reward for quality.
4. study the moisture adsorption characteristics of *Ofada* flakes.
5. determine the goodness of fit of mathematical models for the storage stability predictions.

1.3Justifications for the study

Nigeria is reputable to have comparative resource advantage in rice production (Nkang*et al.*, 2011). Rice imports in Nigeria have represented a good proportion of total food imports overtime (*Diagne et al. 2011*; Nkang*et al.*, 2011) and there exists a threat to the Nigerian economy due to large volume of milled rice imports into Nigeria, with an import bill currently exceeding US$2 billion (IFPRI, 2013).The poor quality of the local rice was revealed as a deterrent to its consumption by households (Bamidele *et al.*, 2010) and paddy processing is considered as a critical point for the determination of the rice quality. Therefore, to reverse the ugly trend an effort should be made to upgrade rice processing conditions coupled with the provision of standard processing facilities. This would help to make the local rice sufficiently more competitive thereby increasing its demand.

According to FAO (2008), it is better to upgrade local technology towards achieving food security and stability. The traditional processing method of Ofada rice was studied with intention to upgrade and optimise the processing operations for better product quality and acceptability. Several investigations have been conducted on effect of specific unit operation (soaking time, parboiling temperature, drying temperature and storage duration) on the quality of rice (Adekoyeni *et al.*, 2012; Chukwu and Oseh, 2009; Patindol *et al.*, 2008; Otegbayo *et al.*,2001; Zhou*et al.*, 2001 and Daniels*et al.*, 1998).In their experiment, single or two of these processing operations were considered.The present study was aimed at investigating the effect of interactions of these various operation units on rice quality. The results of this study would make relevant technical data available on optimum soaking, parboiling, drying, and storage duration for milled rice processing for present and prospective investors that would have relied on "trial and error" method in processing*Ofada* rice and its utilisation for flake production.

Production of ready-to-eat flakes as a breakfast cereal from *Ofada* rice would serve as a new way of harnessing the potential of *Ofada*rice considering its unique taste and aroma. This strategy would bring about nutritional diversification, income generation and poverty alleviation. According to Alakali *etal.*, (2009), adsorption characteristics of moisture isotherm are best for prediction of storage stability of foods rather than desorption. Therefore, adsorption characteristics of ready-to-eat flakes produce from *Ofada* rice is used for moisture isotherm determination.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General background of rice production

Rice is one of the most important cereal crops and feeds more than a third of the World's population (Jouki and Khazaei, 2012). It is a cereal of the family *poaceae* or tufted grass (Kassali *et al.,* 2010), and a monocarpic annual plant that usually grows between 1 and 1.8 m tall with long slender leaves 50-100 cm long and 2-25 cm broad. It's small, wind pollinated flowers which are characteristics of grasses. According to Chang (1976) as reported by Hongyi *et al.,* (2011), rice is believed to have evolved around 130 million years ago, its cultivation started within the last nine thousand years.

Freshly harvested rice is called paddy grain or rough rice. The pearly white starch grain used for cooking is the centre of the rice seed and is covered and protected by the hull. Inside the hull, the familiar white grain is covered by a layer called bran layer. Rice grain with bran is called brown rice and when the bran layer is removed it is called polished rice. According to Abbas *et al*., (2011), the genus *Oryza* comprise about 25 species, distributed in tropical and sub-tropical regions of Asia, Africa, South America, China and Northern Australia. However, there are three major varieties of rice, namely, *Oryza sativa* (Asian rice), *Oryza glaberrima* (African rice) and the WARDA's hybrids rice. *Oryza sativa* is a common specie grown throughout the Asia, Australia, Americas and Africa; the O. glaberrima originated from the wild rice *O. Barthil* some 3500 years ago (Selbut, 2003).

Rice can be grown in a wide range of environmental and soil conditions and is produced in over 100 countries except Antarctica. About 95 % of World's rice is produced in developing countries, 92 % of it in Asia (Abbas *et al*., 2011). However, *O. glaberrima* is grown in small scale in Western Africa especially in the inland of Niger Delta; the Sokoto-Rima Valley and other flood-plains of the extreme north of Nigeria.

It is also a common rice type on the flood-plains of the Benue. *O. glaberrima* is known by different local names as '*Hakorin Montol'*(literally, the tooth of Montol people because of its grain size) in the Plateau/Nasarawa area; and *Jatau* (red) throughout Hausa land and the Chad Basin. Indigenous African rice is one of the least-known major cereals (Murray, 2004) until only recently when scientists using biotechnology techniques began to unlock its great genetic potentials (WARDA, 1999).

Oryza sativa has been cultivated on almost all continents and has been consumed by humans for at least 5,000 years (Bao and Bergman, 2004). The main varieties of *Oryza sativa* include;

Indica- Long grain rice notably on the India sub-continent.

Japonica- A short grained and high in amylopectin (sticky when cooked).

Javanica-This is a broad grained and grown in tropical climates.

China, India and Indonesia were believed to be where rice was first cultivated, and thus the origin of these three races of rice – japonica, indica, and javanica (Juliano, 1993).

Japonica and indica types are considered the two sub-species of rice, and each sub speciecomprised of genotypes with varying cooking and processing properties (Bao and Bergman, 2004; Hizukuri *et al.,* 1989). The short and wide japonica rice typically cook soft, moist and sticky (Bao and Bergman, 2004) and retrograde slowly (Hizukuri *et al*., 1989), whereas the long and thin indica rice usually cook firm, dry and fluffy (Bao and Bergman, 2004) and retrograde rapidly (Hizukuri *et al.*, 1989). Javanica rice belongs to the japonica race (IRRI, 2007). The characteristics of the different rice are controlled by their starch composition.

Portuguese traders introduced Asian rice from East Africa to West Africa some 450 years ago (Jones, 1995). It could have also spread across the Sahara and to northern Nigeria via the oases and the Trans-Saharan trade (Selbut, 2003). According to Selbut, the history of rice cultivation assigned the spread of Asian rice to 1850s at Abeokuta through missionary activities; to 1970s when it spread to Lagos area in Epe and Okitipupa; to after the Second World in Ogoja and Abakaliki provinces; to 1945 in Shaki area of Oyo state; to early 1960s in the Niger Delta area; and to 1954 extended Oshogbo area. Western Nigeria played an important role in the introduction of Asian rice in Nigeria.

The story of rice in West Africa is becoming more interesting in view of the technological breakthrough in the development of hybrid rice by WARDA and other partners (WARDA, 1998;Ng *et al.*, 1991; Jennings *et al.*, 1979). The rice inter-specific hybridisation project has produced NERICA (New Rice for Africa). This is literally at the verge of a rice revolution in Africa as WARDA's Participatory Varietal Selections and Community Seed Production programmes become full-blown. NERICA is a progeny which exhibits a hybrid vigour which has the advantages of both *O. glaberrima* and *O. sativa* surpassing both in many regards (WARDA, 1999).There are large numbers of varieties of rice cultivated in Nigeria. The varieties are distributed based on climate, agricultural practice, and ecology (Table 2.1).

2.2 *Ofada* rice

Ofada rice is a generic name used to describe all rice produced and processed in the rice producing clusters of South West Nigeria named after Ofada, a small rural community in Obafemi Owode Local Government area of Ogun State (Danbaba *et al*. 2011). As a niche and special product originating from certain geographical areas, one of the earliest released varieties was the upland variety FARO 3 (Agbede), which was selected from a complex collection of upland varieties believed to have been introduced by veterans returning from the First World War. As breeding effort continued, OS 6 was introduced from Zaire (Democratic Republic of Congo) and released as FARO 11 to replace Agbede. Additional varieties such as ITA 150 and NERICA 1 have been released as FARO 46 and FARO 55 respectively and are in cultivation in the South West region of Nigeria (NCRI and WARDA, 2007).

Ofada rice could be likened to the popular "basmati rice" from India and Pakistan. It is a unique, unpolished, short grain with red kernel. The unique taste and the aroma of *Ofada* rice have made it to be popular more than other local varieties. There are white and red kernels varieties of *Ofada rice*. The red kernels vary from red to deep red (NCRI and WARDA, 2007). According to NCRI and WARDA (2007) in their investigation on definition of *Ofada* rice qualities through varietal identification and testing discovered that there is a large variation between real *Ofada* and other varieties.

Ofada rice is upland rice grown on free-draining soils where the water table is permanently below the roots of the riceplant. The ecological conditions under which upland rice grows in Nigeria are diverse. However, to obtain successful crop, adequate and assured soil moisture reserves and fertility during key periods of plant growthare essential. The upland rice environments are defined on the basis of soils, climate, water resources, waterregime at the micro level (Rashid-Noah, 1995) and topography. There are two types of Upland Rice Systems (URS) in Nigeria. These are Rainfed upland and Irrigated upland. The rainfed system is common where *Ofada* rice is produced. It is a system common in Abeokuta, Ado-Ekiti, Abakaliki, Ogoja in the south right up to Yauri, Zamfarariver, Gombe, southern Borno and Yola.

Table 2.1: Agronomic characteristics of released rice varieties in Nigeria

Variety	Cultivar source	Ecology	Year of release
FARO 1	BG-79	SS	1955
FARO 2	D-114	SS	1958
FARO 3	AGBEDE	UPLAND	1958
FARO 4	KAV-12	DS	1959
FARO 5	MAKALIOKA	SS	1960
FARO 6	I.G.B	DS	1961
FARO 7	MALIONG	DS	1962
FARO 8	MAS-2401	SS	1963
FARO 9	SIAM-29	SS	1963
FARO 10	SINDANO	SS	1963
FARO 11	OS-6	UPLAND	1966
FARO 12	SML-140/10	SS	1969
FARO 13	IR-8	SS	1970
FARO 14	FRRS-43	DS	1971
FARO 15	FRRS-162-B	SS	1974
FARO 16	FRRS-168-11-2-B	SS	1974
FARO 17	FRRS-148	SS	1974
FARO 18	TJINA	SS	1974
FARO 19	IR-20	SS	1974
FARO 20	BPA-76(BICOL)	SS	1974
FARO 45	ITA 257	UPLAND	1992
FARO 46	ITA 150	UPLAND	1992
FARO 51	CISADANE	IS&SS	1998

SS-Shallow Swamp, DS-Deep Swamp, IS-Irrigated Swamp
Source: NCRI and WARDA (2007

*Ofada*rice has recently gained prominence and is fast gaining international attention. United Kingdom, the department for International Development Programme (IDP), has revealed that a massive potential exists for export of *Ofada* rice to Europe and USA. *Ofada* rice grain quality has assumed much greater importance as its demand for local and export consumption are on increase and consumers placing much emphasis on the quality of the milled rice (Idris *et al*., 2013). The study presented by CMRG - a market research agency, and Emerging Market Economics Limited (EME) based in the U.K, showed that among cities and towns in the South West, Abeokuta in Ogun State recorded a significantly higher consumption level with 58 %, followed by Ilesa in Osun State (38 %), Ado-Ekiti in Ekiti State (34 %), Ibadan in Oyo State (34 %) and Lagos (31 %). Abuja generated 18 % score in this regard thus suggesting that prevalence of*Ofada* rice consumption is in the South-West. Members of the trade and professional buyers also confirm the South-West as the dominant producing and consuming areas for *Ofada* rice (Eme and Nathan, 2007).

Indications from the study established no linkage between *Ofada* rice consumption and any particular traditional/cultural practices. Only a few who eat *O*fada rice at special periods do so at parties and commemorative events. Choice at such times was due mainly to the "natural" and "local" taste/flavour of the rice (Eme and Nathan, 2007). The average household consumer of *Ofada* rice buys 6.46kg of the product per month. Abeokuta (11.62kg) and Ibadan (7.04kg) recorded remarkably higher household volume purchases compared with other locations (Eme and Nathan, 2007). Retailers in the local markets account for the bulk (90 %) of all purchases even though, average quantity bought from this source seldom exceeds 5.09kg. Average monthly expenditure on *Ofada* rice stands at ₦871.70 per household. However, consumers in Lagos far exceeded this limit with average monthly spend of ₦1, 264.00, followed by Ado-Ekiti and Abeokuta with ₦1, 205 and ₦1, 079 respectively (Eme and Nathan, 2007).

However, processing of *Ofada* rice is characterised with various deficiencies ranging from poor production and post harvest practices, poor physical and cooking qualities, presence of foreign materials, and unappealing (Otegbayo *et al.*, 2001). These problems should be eliminated to enhance good market for the product. There are about 340,000 Nigerians living in the UK and a potential demand for 120 tonnes of *Ofada* rice. The fast food companies in Nigeria are hungry for *Ofada*. The market in the US, however, seems to have an even greater potential for growth than the one in the UK.

2.3 Economic importance of Nigeria rice sector

Rice is the leading food crops in World and a favoured cereal in the diet appearing in different forms (Otegbayo *et al.*, 2001). A large array of food and cash crops are cultivated in Nigeria. However, rice has emerged as the fastest growing sector. It is cultivated in virtually all of Nigeria's agro-ecological zones, from the mangrove and swampy ecologies of the River Niger delta in the coastal areas to the dry zones of the Sahel in the North. The land mass used for rice cultivation increased from 150,000 hectares in the 1960s to about 1.8 million hectares currently. Nigeria has depended largely on increasing land area for rice cultivation to improve production (Akande, 2001).

The Nigeria rice sector has witnessed some remarkable developments, particularly in the last ten years bothin rice production and consumption. The demand for rice in Nigeria is, however, growing faster than for any other major staples, with consumption broadening across all socio-economic classes, including the poor. Substitution of rice for coarse grains and traditional roots and tubers fuelled growth in demand at an annual rate of 5.6% between 1961 and 1992 (Osiname, 2002).

The Food and Agricultural Organisation of the United Nations projected growth in rice consumption for Nigeria to remain high at 4.5 % per annum beyond year 2000. The United States Agency for International Development, USAID, in a report entitled "Nigeria rice value chain analysis," had put rice importation at three million metric tonnes annually with a total value of N468 billion ($3 billion). In addition, rice production and marketing in the country contribute to food security, job creation, poverty reduction and national productivity. For instance, the economic impacts of rice production in terms of income and employment are at five main levels production, processing, marketing, food vending and external (import) trade levels (USAID, 2009).

Rice is an economic crop, which is important for household food security, ceremonies, nutritional diversification, income generation and employment (USAID, 2009). The Nigerian rice industry is dominated by small- medium scale processor (Adeyemi *etal.*, 1986). However, in October (2011), Aganga, the Nigerian minister for Trade and Investment announced that rice importation in Nigeria will end in 2014 (Ujah, 2011). Nigeria has used various trade policy instruments such as import restrictions, and outright ban on rice import at various times from 1978 to 1995. This policy will task the resourcefulness of Nigerian rice producers, processors and researchers to improve the quality of local rice to match the current quality of the foreign rice which are found desirable because of their better processing.

2.4 Nutritional profile and utilisation of rice

Rice is an excellent source of energy. It is comprised of 77.5% carbohydrate. Like other cereals, the carbohydrate in rice is mainly in the form of starch- a complex carbohydrate. Starch exists as either amylose or amylopectin and comprises units of glucose (Fennema, 1996). Amylopectin contains branches and is less resistant to digestion whereas amylose is a straight chain molecule and harder for the digestive system to break up. This means that rice varieties with a greater proportion of starch in the form of amylose tend to have a lower glycaemic index. Rice also contains a range of important nutrients, including B and E vitamins; protein;and minerals –especially potassium which helps the body reduce toxins. Rice cancontribute significantly to vitamin and mineral intake, although the contribution tomicronutrient intake will depend on the proportion of germ, bran and endospermconsumed (ie the balance between brown and white rice).

An interesting reason for it being so popular is because of its ease of digestion. Even the sick, elderly and babies can digest this grain very well when cooked. Even people who are allergic to lots of other foods can eat rice. Besides, rice provides 21% of global human per capita energy and 15% of per capita protein. It is low in fat and protein, compared with other cereal grains. Recent studies by the modern nutritionists have compared the easily digestible organic rice protein, a highly digestible and non-allergenic protein to mother's breast milk in the aspect of its nutritious quality and also for the high quantity of amino acid that is common in both rice protein and breast milk. Rice also provides minerals, vitamins and fibre although; all constituents except carbohydrates are reduced by milling. No matter how plausible the reasons by nutritionist for rice consumption, they do not explain the reason behind increasing demand for rice in Nigeria (Erhabor and Ojogho, 2011).

AnOryzanols, a mixture of three different phytosterols have been the main focus of research into the cholesterol-lowering properties of rice. Researchers developed an animal model using hamsters that led to the successful lowering of plasma cholesterol. In this study oryzanol decreased low density lipoprotein (LDL) or "bad" cholesterol by 24 percent when fed at levels consumed by humans. Furthermore, the LDL/HDL cholesterol ratio improved at 37 percent (USDA and USA Rice Federation, 2007).

Rice is mostly eaten steamed or boiled, mashed as porridge, especially for weaning children or cooked rice which is mashed and rolled into balls with soup but it can also be dried and ground into flour in the several pastry preparations such as noodles, flakes (Gayin *et al.*, 2009). Like most grains, rice can be used to make beer and liquors. Rice straw is used to make paper and can also be woven into mats, hats, and other products. The main by-products of rice milling are rice hulls or husk, rice bran, and brewer's rice. Rice hulls are generated during the first stage of rice milling, when rough rice or paddy rice is husked. Rice bran is generated when brown rice moves through the whiteners and polishers. When paddy is hand-pounded or milled in a one-pass Engleberg steel huller, rice bran is not produced separately but mixed with rice hulls. Brewer's rice is separated or produced when milled rice is sifted (USDA and USA Rice Federation, 2007).

2.5Physical properties of quality rice

Physical dimensions of rough rice are used for calculating power requirement during milling. Also physical properties of rough rice could affect its milling quality parameters like head rice yield (HRY) and degree of milling (DOM) (Liu *et al.*, 2009). They investigated the relationships between physical properties (length, width, thickness, aspect ratio, equivalent diameter, sphericity, surface area, volume, bulk density, true density, porosity, and thousand-seed weight) and degree of milling of brown rice varieties during milling process. During rice milling, kernels are exposed to different compressive, bending, shear and frictional forces, and breakage can consequently occur (Shitanda *et al.*, 2002). This breakage causes HRY reduction and economic losses.

The grain length, weight and width determine the physical quality of rice grain. The classification of rice quality is based on the length of grain i.e. short, medium and long grain. Arborio rice grains are high in width and Basmati rice grains are high in length (Adu-Kwarteng *et al., 2003*). According to Adeyemi (2009), two factors contributing to appearance of grain are its length and shape and studies have indicated that minor changes in the length and breadth occur in the grains as a result of parboiling. The ratio of length to width is an important aspect to determine the shape of rice variety (Normita and Cruz, 2002), and grain weight gives the information about the size and density of the grain. The densities of different rice grains affect the cooking quality. It is very important for grain weight to be uniform because it is one of vital determinants of grain quality (Adeyemi, 2009, CRC, 2003).

The appearance always appeal to consumers hence the size, shape and width should be the top criteria to determine the quality of rice and breeders are also consistent to develop new varieties for commercial point of view (Adair *et al.*, 1966).

The length to breadth ratio ranging from 2.5 to 3.0 is widely acceptable and the grain length > 6mm is preferred. The size and shape of rice grain may vary from one group to another group of different regions. Some groups prefer short grains; some prefer medium grains while mostly people like long slender grains in Indian sub-continent regions. Medium short grains are preferred by the peoples of South Asian regions but the long grain rice has also acquired the leading position in International market (Normita and Cruz, 2002).

Appearance, eating, cooking and milling qualities comprise the primary components of rice grain quality and these have shown to be affected by parboiling operations (Saeed *et al.*, 2011). The grain length of milled rice ranged from 4.53mm to 5.07mm and width from 2.43 to 2.62mm. The length to width ratio ranged from 1.84 to 2.09. However, size characteristic obtained by Adekoyeni *et al.*,(2012) using variation of parboiling temperature were 6.31 – 5.48mm, 2.37 – 2.02mm, and 3.05 – 2.85 for length, breadth and width respectively. The varietal characteristics such as shape, size and density affect the quality of rice grain as reported by Juliano and Duff (1989).

Investigation of physical characteristics of aromatic and non aromatic commercial rice varieties grown in Pakistan revealed 7.3 mm as average length for aromatic (basmati), whereas lowest value of 5.8 mm was recorded in JP-5 rice variety (Sagar *et al.*, 1988). According to FAO (2005), the type of milled rice is classified according to the length of the whole grain, thus;

a. Extra long - milled rice of which 80 % of the whole milled rice kernels have a length of 7.0 mm. or more.
b. Long -milled rice of which 80 % of the whole milled rice kernels have a length of 6.0 mm. or more but shorter than 7.0 mm.
c. Medium -milled rice of which 80% of the whole milled rice kernels have a length of 5.0 mm. or more but shorter than 6.0 mm.
d. Short -milled rice of which 80 % of the whole milled rice kernels are shorter than 5.0 mm.

The physical and mechanical properties of rice, which are important in the design and selection of storage structures and processing equipment, depend on grain moisture content. Therefore, the determination and consideration of properties such as bulk density, true density, angle of internal friction and static coefficient of friction of grain has an important role (Jouki and Khazaei, 2012).

2.6 Chemical composition of rice

The rice grain consists of 75-80 % starch, 12 % water and only 7 % protein with a full complement of amino acids. Its protein is highly digestible with excellent biological value and protein efficiency ratio owing to the presence of higher concentration (~ 4 %) of lysine (FAO/WHO, 1998). Minerals like calcium, magnesium and phosphorus are present along with some traces of iron, copper, zinc and manganese (Oko *et al.*, 2012).

In addition to being a rich source of dietary energy, rice is a good source of thiamine, riboflavin and niacin. Although the nutritional values of rice varies with different varieties, soil fertility, fertilizer application and other environmental conditions, the following trend still exist by comparison with other cereals: low fat content after the removal of the bran, low protein content (about 7-10 %), and higher digestibility of the protein. Freshly harvested rice grains contain about 80 % carbohydrates which include starch, glucose, sucrose, dextrin, etc. Varieties of rice with high protein and vitamin (vitamin A) content have been obtained through genetic engineering (Yousaf, 1992).

The most important quality criterions based on chemical characteristics are moisture, crude protein, crude fat, crude fibre and ash contents. The grain may absorb moisture in storage depending on the storage condition and this might affect the keeping quality of rice (Daniels*et al.*, 1998). The colligative properties of rice also depend on the amount of moisture available for hydration in the grain and also determine shelf life stability because all grains have to be stored for a certain period before their end use. The grains having high moisture content are difficult to store safely because these are more susceptible to attack a pests and diseases. The moisture content can be measured by oven drying (AOAC, 2000) and it is expected to keep paddy at 14 % moisture content for longevity and milling quality (Adeyemi, 2009).

Chemical compositions of cereals are characterized by protein content. Micro-kjeldahl analysis and different methods are used to determine the protein content in rice. The protein content is affected by environmental conditions, such as soil and applicability of nitrogen fertilizer. Protein in cereals is mainly present in bran and periphery of the endosperm.

Rice protein contains most of the essential amino acids which provides the well balanced proportion for humans. It is evident that the amount of protein in rice is not very high but the quality of rice protein is far better than other cereals because it is more nutritious (about 4-5%) lysine which is higher than wheat, corn and sorghum (James and McCaskill, 1983; Janick, 2002). Araullo *et al.*,(1976) as reported by Muhammad (2009) stated that the edible portion of brown rough rice consists of about 8% protein and milled rice contains 7% protein. The protein content in Pakistani rice ranged from 7.38 to 8.13% as reported by Awan (1996).

Fat is the main source of food energy. Rather than giving energy it also helps in the absorption of fat soluble vitamins. The body requires fatty acids and these can be synthesized from carbohydrates, proteins and fats except one fatty acid known as linoleic acid. Linoleic acid contains almost 30% of the total amount of fatty acids in rice. Rice contains very low amount of fat but cooked brown rice contains higher fat contents than white rice (American Rice Inc, 2004). The fat content ranged from 0.50 to 2.23% in rice (Taira and Lee, 1988; Sotelo *et al.,* 1990; Tufail, 1997).

The professionals recommend the 25 g of fibre per day for the reduction of chronic diseases. The foods rich in fibre enhance the stomach functions and also reduce the intestinal dilemma. The half cup of cooked brown rice contains 1.8g dietary fiber which is higher than cooked white rice that contains 0.3g dietary fiber (American Rice Inc, 2004). The fiber content in different Pakistani rice varieties varied from 0.20 to 0.35% (Awan, 1996; Tufail, 1997). The fibre content in brown rice after milling was found to be 1.9±0.6% (Sotelo *et al.,* 1990).

The purity of flour is evaluated by the content of ash in flour. The ash content ranged from 0.57-0.82% in Pakistani five fine varieties of rice and one coarse variety (Awan, 1996). The ash content ranged from 0.55 to 0.78% (Sotelo *et al*., 1990). The chemical and nutritional compositions of rice are usually affected by various processing and storage conditions as concluded by authors in their various findings. Ibukun (2008), in its work on effect of prolonged parboiling duration on proximate composition of rice indicated that there was a decrease in vital constituents such as proteins, and mineral elements as a result of prolonged parboiling duration. Variation in the parboiling temperature leads to variation in the nutritional contents of rice as demonstrated by protein which showed a decrease from 6.61 to 5.29 % after the parboiling operation (Chukwu and Oseh, 2009).

The result obtained for vitamins A and C also showed decrease in values after parboiling at different temperatures of 80, 100, and 120°C. Digestible protein and crude fibre contents are the major determinants of metabolizable energy contents (Ambreen *et al*., 2006). They study chemical composition of rice polishing from different sources available in Pakistan. It wasdeduced from their investigation that among the plant protein feedstuffs and mill by-products, the highest gross energy is from corn gluten meal, followed by rice polishingused in poultry rations as an energy source. Inverse correlation of ether extract was found with crude fiber, calcium and phosphorus. In polished rice, the metabolisable energy calculated was 2237 kcal/kg. Ether extract had an inverse significant correlation with crude fibre ($p<0.01$), calcium ($p<0.01$) and phosphorus ($p<0.05$). High fat content in the rice polishing, especially of unsaturated nature tends to develop rancidity quite readily (Singh and Panda, 1988).

2.7 Mineral profile of rice

There are two forms of minerals: macro and trace minerals. Macro means "large" which are required in larger quantity by the body as compared to trace minerals which are required in small quantities. The examples of macro minerals are i.e. calcium, phosphorus, magnesium, sodium, potassium, chloride, and sulphur. However, the human body also requires trace minerals including copper, iron, cobalt, manganese, iodine, zinc and selenium. The mineral composition of rice may be affected by the environmental and area locations (Malomo *et al*., 2012).

Watt *et al.,* (1989)reportedthe following mineral contents in 12 samples of Canadian wild rice; Phosphorus 0.28%, potassium 0.30% Magnesium 0.11 %, Iron 17ppm, Manganese 14ppm, Zinc 51ppm and Copper 13ppm. Chukwu and Oseh, (2009), investigatedresponse of nutritional content of rice to parboiling temperatures. The result showed that the Zn, Fe, Ca contents of rough IR- 8, long-grained variety are 1.62 ppm, 1.75 ppm, and 3.29 ppm respectively but on parboiling the contents varied with degrees of parboiling temperatures.

Comparative analysis of the mineral contents of local and newly introduce rice varieties grown in Ebonyi State, Nigeria revealed that the phosphorus content varied widely from 0.50 – 0.55 %, the newly introduced had the highest value of phosphorus (0.55 %), followed by “Sipi”, “Canada”, “FARO 15(II)”, “Chinyereugo” and “E4077” (all of which had a mean phosphorus content of 0.54 %), while “MASS II” had the least value of phosphorus (0.50 %) among the rice cultivars. The potassium, sodium, calcium and magnesium values obtained in the 20 rice cultivars ranged from 0.15 – 0.23 %, 0.09 – 0.17 %, 0.07 – 0.25 %, and 0.07 – 0.25 %, respectively (Oko *et al.*, 2012).

The variability observed in the mineral composition was neither restricted to the ecological zones from which they were collected nor peculiar to the newly introduced rice cultivars, though the mineral content was also high in most of the newly introduced rice varieties. Significant correlations ($p = 0.001$) were found only between Na and P, though the correlation coefficient was only moderate (42.1 %) (Oko *et al.*, 2012).

Sotelo *et al.*, (1990) determined the mineral contents of 12 Mexican varieties of rice after milling. Polishing of the rice significantly reduced the potassium, Iron and zinc contents. Significant variation was found between varieties of brown and white rice in mineral contents. Noreen *et al.*, (2009), conducted a research on chemical composition of rice cultivars (Swat-1 (S-1), Basmati- 385 (B-385), Dilrosh- 97 (D-97), JP-5 and Fakhr-e- malakand (FkM)) subjected to common cooking processes and were assessed for their comparative nutrition. Analysis of rice grain showed appreciable amount of sodium (155mg/ kg), zinc (37.5 mg/kg), phosphorus (381 mg/kg), potassium (1908 mg/kg) and copper (3.29 mg/kg). Variation among varieties in respect of nutrients and phytic acid was found non- significant.

Soaking and boiling processes caused significant decrease in phytic acid, sodium and phosphorus contents in all varieties. Cooking process decreased the concentration of phytic acid,potassium and zinc. Phytic acid was reduced by 26% due to boiling and 21% due to soaking for 30 minutes. Marr (1995) analyzed ninety samples of brown rice (Australian) for P, K, S, Mg, Ca, Na, Al, Cu, Fe, Mn, Mo, and Zn. The manganese content in Australian rice was higher in brown rice grown in other countries. Other elements concentrations were in a similar range to those reported for overseas rice. Highly significant correlations were found between levels of P, K, Mg, and S of rice varieties.

Mostly the iron is present in the form of haemoglobin in human body. The function of haemoglobin is to carry oxygen to the body tissues for the oxidative reactions in the body cells. Iron is also an essential constituent for so many enzymes to perform their function especially for the breakdown of glucose and fatty acids to release energy. Half cup of cooked brown rice provides 8% of iron as compared to white rice which gives 7% (American Rice Inc, 2004). Potassium plays very vital role for the synthesis of proteins and cell functions. The cooked brown rice provides greater intake of Potassium as compared to cooked white rice because cooked white rice contains low content of potassium (American Rice Inc, 2004).

2.8 Physical and chemical properties related to processing and eating quality of rice

Milled rice contains about 90% starch. In rice starch, amylose has a greater effect on the processing properties and eating quality. Amylose is directly correlated to the hardness, whiteness and dullness of cooked rice and volume expansion and water absorption during cooking. Varieties with a low amylose level have a soft and sticky cooked texture while those with high amylose content have flaky and hard texture (Juliano, 1985). Rice varieties are usually classified in terms of amylose content as waxy (1-2% amylose), very low (2-9%), low (10-20%), intermediate (20-25%), and high (25-30%) (IRRI, 2007).

Waxy rice occurs in both japonica and indica rice sub-species (Bao and Bergman, 2004). Amylose content is the most important physicochemical property of rice related to its cooking and eating quality, gelatinisation temperature also affects consumer preference and acceptance of a rice variety because gelatinisation temperature is directly associated with cooking time (Juliano, 1993). Heat energy needed to completely gelatinize starch, on the other hand, is important for food processors, because this determines the heat input, cooking time, and temperature of processing (Bao *et al.*, 2007).

In rice, the ratio of the starch fractions (amylose to amylopectin) along with the protein was established to have the major influence on cooking and eating quality of the grain (Zhou *et al*., 2001). According to Desikachar (1975), high gelatinization temperature in rice has been considered as an undesirable property, because it prolongs the cooking time of rice during processing. Rice granules, on average, are the smallest of the commercial starch granules (1.5-9μm), although the small granules of wheat starch are almost of the same size. All starches retain small amount of protein, ash, lipid (Fennema, 1996).The poor viscosity, high rate of retrogradation and poor clarity may be due to absence of phosphate ester groups in cereal starch. Cereal starch contains endogenous lipids in the granules. These internal lipids are primarily free fatty acids (FFA) and lysophospholipid (LPL), with ratio of FFA to LPL varying from one cereal starch to the other (Fennema, 1996).

2.9Grading requirements for paddy and milled rice

Grading of milled rice either for foreign or domestic consumption is usually done after milling. Periodic inspection, however, is conducted during milling to check if the resulting product meets the required standard specifications. This makes possible the immediate restoration of a good process and prevents production of too many defective grains or rejects. However, the grading is based mostly on physical characteristics of rice. Grade requirement for paddy and milled rice as provided by FAO (2005) are presented in Table 2.2 and 2.3 respectively.

2.10 Methods of processing rice

Processing of rice started from farm gate where rice is sorted according to variety. The rice paddy is separated from the stalk by the process known as threshing. This operation can be performed either manually or mechanically. The traditional method of threshing is achieved by human trending on the panicles or flailing the stalks by hand (Adeyemi *et al*., 1986). Pounding of rice stalks in bags is also practiced in some locality. This operation is followed by winnowing to remove the shafts and other foreign materials present. There are two methods in the processing of paddy; the non-hydrothermal (non parboil) and hydrothermal (parboil) methods.

The non hydrothermal processing of rice requires direct milling of paddy to obtain milled rice. This is the most common method in rice processing. Before milling the paddy, grains must be dried to decrease the moisture content to between 18 – 22 %. This is usually done with artificial heated air or with the help of naturally occurring sunshine (Daniel *et al*., 1998). They recorded the effect of pre-drying and drying condition on the head rice yield, cooking properties and starch functionality of processed rice. The study revealed that delay in drying of paddy affect the quality characteristics of the rice starch.

Rice that has been subjected to hydrothermal treatment prior to milling is termed parboiled rice (Patindol *et al*., 2008). Parboiling account for about 15 % of the World's milled rice (Bhattacharya, 2004), and its market has been increasingespecially in industrialized countries (Patindol *et al*., 2008). It belong to the most popular rice products in Europe and there is also a high demand for parboiled rice in Saudi Arabia, Turkey, Thailland, Ghana while Nigeria is known majorly for the consumption of parboiled rice (Vegas, 2008; Tomlin *et al*., 2005; Otegbayo *et al*., 2001).

Table 2.2: Grade requirements for paddy

Grading factors	Grade premium :1:2:3
Purity (Min. %)	98.00: 95.00: 90.00: 85.00
Foreign Matter (Max. %)	2.00: 5.00: 10.00: 15.00
a) Weed Seeds and other Crop seed(Max. %)	0.10: 0.10: 0.25: 0.50
b) Other Foreign Matters	1.90: 4.90: 9.75: 14.50
Defectives:	
Chalky and Immature Kernels (Max. %)	2.00: 5.00: 10.00: 15.00
Damaged Kernels (Max. %)	0.25: 1.00: 3.00: 5.00
Contrasting Types (Max. %)	3.00: 6.00: 10.00: 18.00
Red Kernels (Max. %)	1.00: 3.00: 5.00: 10.00
Discoloured Kernels (Max. %)	0.50: 2.00: 4.00: 8.00
Moisture Content (Max. %)	14.00: 14.00: 14.00: 14.00

Source: FAO, 2005

Table 2.3: Grade requirements for milled rice

Grading factors	Grade premium: 1: 2: 3
Head rice (min. %)	95.00:80.00:65.00:50.00
Big broken (max. %)	3.00: 10.00: 10.00:20.00
Broken other than big broken (max. %)	1.90: 9.75:24.00:29.00
Brewers (max. %)	0.10: 0.25: 0.50: 1.00
Defectives:	
Damaged kernels (max. %)	- : 0.25:0.50: 2.00
Discoloured kernels (max. %)	0.50: 2.00: 4.00: 8.00
Chalky and immature kernels (max. %)	2.00: 5.00: 10.00: 15.00
Contrasting types (max. %)	3.00: 6.00: 10.00: 18.00
Red kernels (max. %)	- : 0.25: 0.50: 2.00
Red streaked kernels (max. %)	1.00: 3.00: 5.00: 10.00
Foreign matter (max. %)	- : 0.10: 0.20: 0.50
Paddy (Max. No. Per 1000 grams)	1 : 8 :10 :15
Moisture content (max. %)	14.00: 14.00: 14.00: 14.00

Source: FAO, 2005

Processing of rice using parboil method include the soaking, steaming/parboiling, drying and milling.Paddy is usually soaked in either cold or warm water depending on the traditional practice of the area with the main purpose of hydration of paddy (Adeyemi*et al*, 1985). Ayelogun and Adegoyega(2000) suggested that soaking should not be prolonged to avoid fermentation which affects colour, taste and odour of rice. Igbeka *et al.,* (1991) reported that soaking parameters like soaking time, degree of hotness and moisture content after soaking influence translucency, colour and deformed grains.Adeniran *et al.,* (2012) suggested inoculation of certain microorganism during soaking to prevent growth of microorganisms which may induce bad characteristic flavour into the paddy during soaking.

Drying is traditionally done under the sun. Sun drying involves spreading of the paddy on ground, road side on a raised platform in thin layers of 2 - 3 cm to expose it to solar radiation. This method is low cost but suffers from various drawbacks. It is labour intensive, entirely weather dependent and in rainy or damp weather, drying is unduly delayed causing spoilage, exposure of paddy to birds, rodents and contaminations with foreign materials, also drying is not uniform (Bhattacharya and Ali, 1990; Singhal and Thiersten, 1982). Mechanical drying is a better option which entails forcing heated air through the parboiled rice to evaporate and remove moisture (Ray, 1999). The system consist of an air heating device (electrical heater, furnace or burner) a fan and drying chamber with appropriate air duct. The drying can be carried out in batches or continuous flow system. Solar dryer uses solar energy collector for heating the air and is been adopted as alternative to mechanical dryers. Adeyemi *et al.,*(1985) recommended low drying temperature for better rice quality.

2.10.1 Effect of parboiling on quality of rice

Parboiling as rice processing method is recently popular especially in Africa and it is the usual rice processing method widely practiced in Nigeria (Adeyemi *et al.,* 1986). The parboiling method of rice processing varies from locality to locality but the same trend of processing units. Parboiling is a process developed for improving rice quality. It consists of soaking, steaming and drying of the rough rice. The major reasons for parboiling rice include higher milling yields, higher nutritional value and resistance to spoilage by insects and mould (Cherati *et al.*, 2012). The parboiling process is applied to rice with a preliminary objective of hardening the kernel in order to maximize head rice yield in milling. Besides milling yield, it alsobrought about the realization of the nutritional and health benefits of parboiled brown rice compared to raw brown rice that created the awareness and importance of parboiling among consumers and manufacturers. Also, nick percentage is reduced significantly, yield percentage increases, and because of leakage and penetration of bran into the rice seed, bran percentage is reduced significantly and crust percentage is reduced slightly to, which justifies yield percentage improvement (Saeed *et al.*, 2011).

Traditionally, parboiling involves soaking the paddy in cold or warm water with the duration of steeping varying from 4 to 5 days for cold steeping or overnight for warm steeping. During soaking, water penetrates the endosperm of paddy and forms hydrates by hydrogen bonding. The grain swells which causes increase in the volume of the paddy. Steaming of paddy is carried out in metal drums or earth ware pots until splitting of the husks is observed which takes between 15 and 20 min. The surface area exposed to hydration is increased and the granules swell in an irreversible manner, a phenomenon known as gelatinization. The paddy is then drained and sundried on raffia mats or concrete floors. Drying is completed when grains selected at random give a sharp cracking sound on breaking with teeth. Milling is mostly in Grantex dehuller after which the milled rice packaged and ready for sale (Bhattacharya, 2004; Adeyemi *et al.*, 1986).

Recently, more sophisticated procedures such as dry-heat parboiling and pressure parboiling have been applied (Bello *et al.*, 2004). Patindol *et al.*, (2008), used laboratory scale autoclave at different temperatures (100, 110 and 120°C). Parboiling brings about gelatinization of rice starch, elimination and filing rice seed chaps, which results in improved resistance of seeds against exerted tensions, during paddy threshing or milling operations (Cherati *et al.*, 2012).

2.11 Recent frontier technology in rice processing

Recently the traditional processing of rice has received certain technological improvement. Pressure parboiler and warmer for soaking are commonly employed in modern processing time. The use of fluidisation techniques (Soponronnarit *et al.*, 2006) and ohmic heating (Sivashanmugan and Arivazhagan, 2008) have been documented. Kaasova *et al.*, (2001) reported the effect microwave treatment on physical and chemical changes in rice. The result revealed that microwave treatment of rice before processing reduced drying time of rice and the stability of total starch content.

The gelatinisation of rice starch is progressing faster during microwave treatment than during conventional treatment. Effect of varying the degree of parboiling temperature on quality of rice using a fabricated parboiler was recorded by Islam *et al.*,(2003). The use of low steaming temperature was recommended to both household and commercial parboiling plants in their production of a good quality product. Enzymatic polishing of rice using xylanase and cellulose produced from *Aspergillus sp*. and *Trichoderma sp*. was also investigated and found effective in rice polishing (Mithu *et al*., 2008).

2.12 Production of rice flakes

The basic commodity of most diets of the World is the grains which are made into cereals, flours and "value added "products. Flakes are generally referred to as breakfast cereals and there are two main classes: those requiring cooking, common in China, Japan and many African countries, and those precooked, ready-to-eat flakes, common in Europe and USA (Matz, 1970). A number of different processes are used in the preparation of ready to eat cereals, including flaking, puffing, shredding, and granule formation (Lu and Walker, 1988). In the ready-to-serve category of such products wheat, rice and oat are used at 30%, 11%, and 22% respectively. Ready-to-cook cereals are generally cracked or crushed or may be rolled or flaked grains. The finer the particle processed the shorter the cooking period required.

Methods for production of flakes vary with culture and food habit of people in a particular area. Information on manufacturing of flake is scarce unless those that are patent. Rice flakes are prepared from paddy. It is also popularly known as "Poha". It is a fast moving consumer item and generally eaten as breakfast item. It can be fried with spices and chilly to make hot and tasty food item or milk or curd is mixed with it and then eaten. It is also usedin large quantities for making 'Chevda' (a farsan item) and many caterers use it for thicknessof gravy. Since it is made from paddy, it is easily digestible. Most of its preparations can bemade at a short notice and hence bulk of the households stores it on regular basis. With proper storage, its shelf life is 2-3 months. This is a common product and can be produced anywhere in the country.

Another method of producing rice flakes was reported by Beston and Kirk (1978) involves dehydration of aqueous slurry of substantially completely gelatinized rice starch granules and dehydration of a minor proportion of admixed ungelatinized rice starch granules. The dehydration is concurrently effected with a drum dryer. The dried sheet of substantially completely gelatinized rice material from the dryer is then subdivided into flakes or small platelets which require only the addition of hot water to quickly rehydrate to form a cooked rice product having the appearance and textural quality approaching that of freshly cooked mashed potatoes.

Recently, fish flake is another desert in most places. It is an Intermediate Moisture (IM) fish product which is made from stingray meat, tapioca starch and curing ingredients. In their preparation, tapioca starch is used as a binder in order to achieve a good texture product. Tapioca starch contributes to texture enhancement, binding properties and improved mouth feel to meat products. It is relatively simple to process, it has own characteristic taste and stable without refrigerator (Mardiah *et al.*, 2010). Preparation of fish flake from fresh stingray (*Himantura gerrardi*) was described in the flow chart below by Mardiah *et al.*, (2010).

A number of different processes are used in the preparation of ready-to-eat cereals, including flaking, puffing, shredding, and granule formation- generally of wheat, corn and rice (Lu and Walker, 1988). Lu and Walker, (1988), in laboratory preparation of ready-to-eat breakfast flakes from grain sorghum flour, the manufacturing processes include, mixing the ingredients and hydration to form paste, extrusion, cutting to pellets, cooking, tempering, flaking using heavily spring object, roasting, cooling, and packaging.

2.12.1 Quality characteristics of flakes

Recently, more demand can be seen in the present market for rice based products than for wheat based products and the reason for this could be seen as that the people are even more aware of the peculiar nutritional values of rice as well as its ability to cope with the disorders like diabetes, and also of the qualitative aspects of rice than before. Along with the new trends in rice processing, rice based products of similar quality could be obtained in the near future and, in the present day context, some of the traditional rice processing methodologies are being modernized (Bandara *et al*., 2007).

Very limited literature is available on the organoleptic evaluation and instrumental (objective) methods of measuring texture of flakes. Sensory evaluation of the rice flake-based products showed that colour, texture, rice flavour, and rice aroma were attributes of the rice flakes which contributed to the general acceptability of the products. Blanshard and Mitchell (1988) found a high correlation between textural preferences and sensory crispness, indicating that the acceptability of a food's texture increased with increasing crispness.

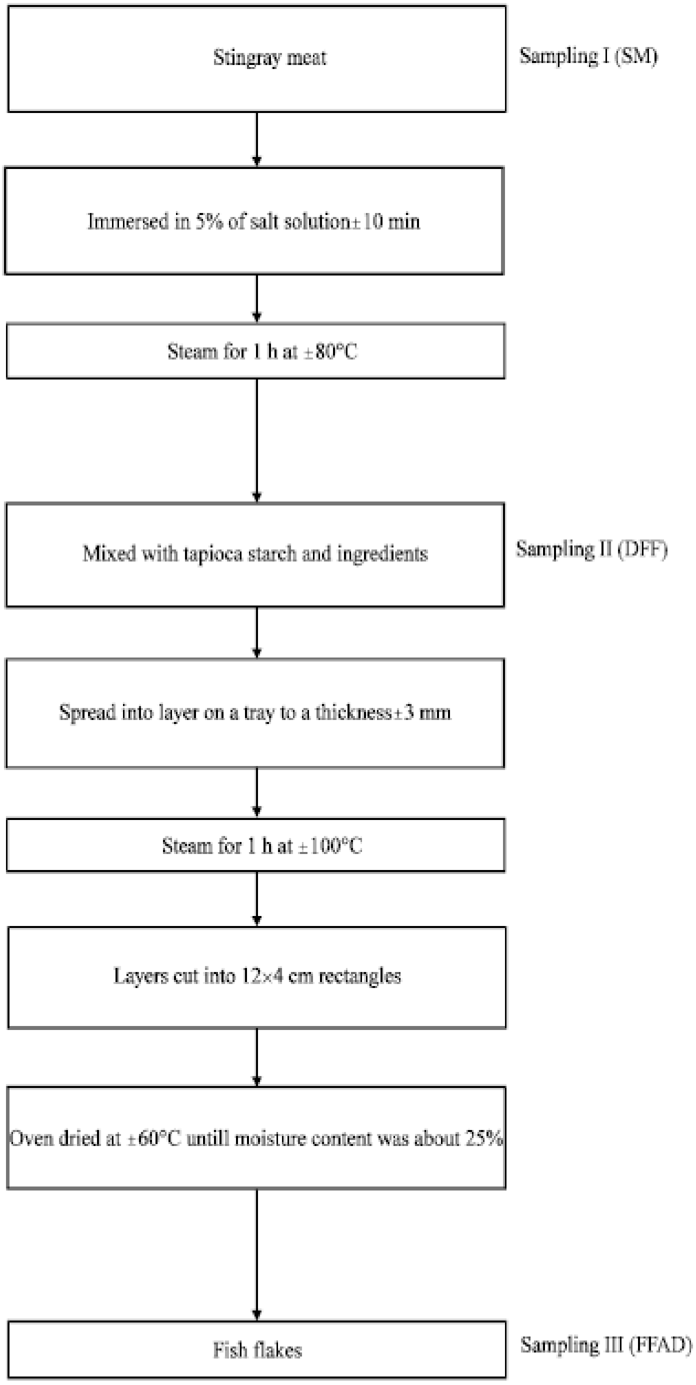

Fig.2.1 Preparation of fish flake

Source: Mardiah *et al.*, (2012)

Sensory evaluation and consumer study of flakes prepared from grain sorghum flour indicated that they were palatable and acceptable to many people (Lu and Walker, 1988). Vickers (1983) observed that crispness was closely associated with the pleasantness of biting sounds. Vickers (1985) has used a bite test cell in an Instron Universal Testing Machine to determine the force – deformation behaviour of eight ready-to-eat breakfast cereals and potato chips. Seymour (1985) used a Kramer shear cell in an Instron to crush samples of several dry crisp foods altered in crispness by humidification. The measurements of peak force, slope and area under the force - deformation curve had small negative correlations with sensory crispness (Vickers 1987).

However, a combination of the physical, chemical, and sensory data revealed that the rice flakes made from waxy rice harvested at 100 day of maturity is better since it has the highest protein and dietary fibre content as well as the lower phytate content.

2.13 Response surface methodology

Response Surface Methodology, an experimental strategy initially developed and described by Box and Wilson, has been employed with considerable success in a wide variety of situation (William and William, 1966). In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response (Akinoso *et al.*, 2010). Box and Wilson suggest using a second-degree polynomial model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process.

Optimization is an act of making the best combination of elements or variables selected to synthesize a system in order to yield the best result (Olaoye and Oyewole, 2012). Optimization techniques also adjust parameters so as to attain a desired result.An optimization problem requires the determination of the optimal (maximum and minimum) values of a given function called the objective function under a given set of constraints. One of the most widely used optimization techniques is the response surface methodology (Akinoso and Adeyanju, 2010). Olayemi (1998) described a regression analysis as an attempt to measure the amount of change (in value) of the dependent variable which is derived from a unit change (in value) of the independent variable. In other words, a regression analysis is an attempt to find out, in a specific way, how one variable is related to the other and it involves a one way cause and effect relationship.

Response surface methodology has an effective track-record of helping researchers improve products and services. To determine the factor levels that will simultaneously satisfy a set of desired specifications. To determine the optimum combination of factors that yields a desired response and describes the response near the optimum.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental design and paddy processing

Ofada paddy (OS 6) was purchased at farm gate in Mokolokin, Obafemi Owode, a renowned area for *Ofada* rice production. The processing unit operations (soaking, parboiling, drying) used as treatment was adopted from the methods of processing of paddy adopted by the rice farmers in the area. D-Optimal response surface methodology was used for the design of the experiment (Montgomery, 2005). The independent and levels of variables were decided mainly from literatures (Adeniran *et al.*, 2012, Chukwu and Oseh, 2009, Patindol *et al.*, 2008, Otegbayo *et al.*, 2001) and on the preliminary investigation on the processing of rice in the area (Table 3.1). The paddy wascleaned within 12 hours, mixed thoroughly and stored in a dry cool place for processing at 1, 5 and 9 months as described in the experimental design.

The major processing operations in the processing of rough rice are soaking, parboiling/steaming, drying, and milling (Fig. 3.1). The paddy was cleaned by winnowing to remove the chaffs and immature rough rice. Paddy (4kg) was soaked in cold water at ambient (28 ±2°C) for typically 1, 3 and 5 day(s) to hydrate the kernels. The soaked paddy were parboiled at varied temperatures (80, 100, and 120°C) at constant pressure using autoclave for 15minutes. The parboiled paddies were tempered for 30 min to cool and air dried in oven at 30, 50 and 70°C. The rice samples were milled (hulling and debranning) in grantex cono disc milling machine. The rice obtained were subsequently ground in a hammer mill, sieved (200 micron size) and analysed.The design of the experiment of the treatment combinations is presented in Table 3.2.

Table 3.1: Independent variables and levels of *Ofada* rice processing

Variables	Levels		
Soaking time (days)	1	3	5
Parboiling temperature (°C)	80	100	120
Drying temperature (°C)	30	50	70
Storage duration (months)	1	5	9

Paddy rice

↓

Soaking

↓

Parboiling

↓

Drying

↓

Milling

↓

Cleaning/Winnowing

↓

Bagging

Fig. 3.1 Processing of *Ofada* rice (Otegbayo *et al.*, 2001)

Table3.2:Experimental design for the treatment combinations

Run	A:Soaking time Day	B: Parboiling temp. °C	C:Drying temp °C	D:Storage duration Month
1	1	120	70	1
2	1	80	70	1
3	5	80	30	5
4	5	80	30	1
5	3	80	30	9
6	5	80	50	5
7	1	120	30	5
8	5	80	70	1
9	3	120	70	9
10	3	120	50	5
11	5	120	30	9
12	1	100	50	5
13	3	120	70	5
14	1	100	50	9
15	5	120	50	9
16	1	120	70	1
17	3	100	50	5
18	5	100	50	5
19	1	80	30	1
20	1	120	30	1
21	5	100	30	9
22	1	80	70	5
23	5	80	70	9
24	1	80	30	9
25	1	120	30	1

3.2 Production of *Ofada* rice flakes

The production of the flakes was carried out as described by Lu and Walker (1988). The milled rice was cleaned and ground into flour. The flour was sifted with sieve (60-mesh testing sieve) and the coarse residues were discarded. Flour (400g) was mixed with 300 ml of water, 25g of sugar, and 4g of salt in a kitchen KENWOOD mixer for 5 min. The dough was placed in a pasta extruder attachment and forced through a die with 5-mm hole. After the extrusion, it was cut 0.5 cm long pellets, and steamed using a pressure cooker for 15 min. After cooking, the pellets were tempered and pressed through a heavily spring roller. The resulting flakes were toasted on pans at 200°C for 20 min, cooled, and packaged in plastic as shown in Figure 3.2.

Rice flour

↓

Mixing(sugar, salt, water)

↓

Extrusion (3mm thick; 5mmhole)

↓

Cutting

↓

Steaming

↓

Tempering (overnight at 5ºC)

↓

Flaking (pressing)

↓

Roasting (200ºC, 20min)

↓

Cooling

↓

Storage

↓

Ofada rice flake

Fig.3.2 Production of rice flakes (Lu and Walker, 1988)

3.3 Determination of physical properties

Physical properties of the rice appraised were size characteristics (length, width, and breadth), head rice percentage, percentage chalkiness, brokenness, and colour. These were analysed as described below.

3.3.1. Size characteristics

Size characteristics were determined as described by Patindol *et al.*, 2008 and Gayin *et al.*, 2009. Linear dimensions (length, breadth and the width) of 100 grains were measured with digital vernier callipers with accuracy of 0.05mm.The mean of the 20 measurements were recorded.

3.3.2 Thousand grain weight

This was carried out by counting 100 kernels and weighing them on an electronic balance weighing machine and then multiplied by 10 to give the mass of 1000 grains as show in equation 1(Nalladulai *et al.*, 2002 and Gayin *et al.*, 2009).

TGW= Weight of 100 grains of rice x 10 **(1)**

3.3.3 Head rice yield

The parboiled rice was shelled and milled using laboratory miller, which separates whole and broken grains. The head rice yield (HRY %) was calculated (equation 2) as percentage of whole milled grains respect to parboiled rough rice, the average value of the duplicates was calculated (Patindol *et al.*, 2008).

$$\text{Head rice (\%)} = \frac{\text{Weight of whole grains}}{\text{Weight of paddy samples}} \times 100 \quad \text{-----------------------------} \quad \textbf{(2)}$$

3.3.4 Percentage chalky rice

The percentage rice chalkiness was calculated from five replicates of 100g samples, according to the method outlined by WARDA (1995) (equation 3).

$$\text{Chalkiness (\%)} = \frac{\text{Weight of chalky grain}}{100\text{g}} \times 100 \quad \textbf{(3)}$$

3.3.5 Percentage broken grain

Percentage broken grain was determined by the method of WARDA (1995). 10g of milled rice was sampled from the lot and the broken kernel was separated from the whole grains. The percentage of the broken grains was computed using the equation 4:

$$\text{Broken grain (\%)} = \frac{\text{Weight of broken grains}}{\text{Weight of paddy samples}} \times 100 \quad \textbf{(4)}$$

3.3.6. Determination of colour of rice flour

The colour was determined by the method described by Akintunde and Tunde-Akintunde (2013) using a portable PCMTM colour Tee colorimeter (SM3002421). The instrument was first standardized with a white A4 paper. The instrument software was configured to read the desired scale or index. Three grams of the sample was weighed into a transparent bag and the reflected rays sent the signal to the tri-stimulus filter which was connected to the phototubes. The colour measurement circuit records L, a, and b coordinates which were then converted to colour coordinates L*, a* and b* values which were recorded and the lightness and colour values were calculated using equation 5:

$$\text{Colour value, B} = \sqrt{(a*)^2 + (b*)^2} \quad \textbf{(5)}$$

The L,a,b type of scales simulate this as:

L (lightness) axis – 0 is black, 100 is white

a(red-green) axis – positive values are red; negative values are green and 0 is neutral b(yellow-blue) axis – positive values are yellow; negative values are blue and 0 is neutral

3.4 Determinationof chemical composition of *Ofada* rice

The chemical composition of rice determined include proximate composition (protein, fat, ash, crude fibre, carbohydrate, moisture) and other chemical constituents were amylose, metabolisable energy, free fatty acids, and phytate. The methods for the analyses were described below:

3.4.1 Determination of moisture content

The moisture content was determined by the method described by AOAC (2000). Five grams of each sample was weighed into pre – weighed clean drying dish. The dish was placed in a well ventilated laboratory hot air oven (Surgifriend Medicals, England. SM9053) maintained at 105^{0}C. The weight of the sample plus the drying dish was checked at hourly interval after the first two hours until the decrease in mass between successive weighing did not exceed 0.05mg per g of sample. The loss in weight was reported as the moisture content and calculated using equation 6:

% Moisture content = Moisture Content, (%) $= \frac{M1-M2}{M1-M0} \times 100$ **(6)**

Where M_0 = weight of the empty dish before drying

M_1 = weight of the dish and the sample before drying

M_2 = weight of the dish and the sample after drying.

3.4.2 Determination of protein content

The crude protein was determined using micro Kjedhal method as described by AOAC (2000). Approximately 1g of the sample was weighed into the digestion tube of Kjeltec 2200 FOSS Tector Digestion unit (Foss Tecator Analytical AB Hoganas, Sweden). Two tablets of catalyst (containing 5g of K_2SO_4 and 5mg of Se) were added and also 12ml of concentrated H_2SO_4 added. Digestion was done for one hour at 420^0C. The distillation was done using 2200 FOSS distillation unit with addition of 80mls of water, 40 ml NaOH (40%). The distillate was collected in 4% boric acid prepared with bromocresol green and melthyl red indicators. The distillate was titrated with 0.1 M HCl. Equation 7 was applied.

$$\text{Nitrogen, (\%)} = \frac{(\text{Titre} - \text{Blank})\text{x } 14.007 \text{ x } 0.1 \text{ x } 100}{1000 \text{ x sample weight (mg)}} \quad \textbf{(7)}$$

Crude Protein, % = %N multiplied by 5.95

3.4.3 Determination of fat content

The fat contents were determined using the method described by AOAC (2000). The principle of Soxhlet fat extraction method was used but with a modern fat extractor with automated control unit (Foss Soxtec 2055, Foss Tecator Analytical AB Hoganas, Sweden). The equipment has the advantage of analysing the fat contents of six samples in 1h: 15min compared to the conventional Soxhlet which takes up to 8 h.The equipment has six extraction units with each unit having thimble for loading the samples and aluminium cups where the extracted fat are collected. The differences in the weight of the pre-weighed cups and after extraction are estimated as the percentage of fat in the samples. 1 g of the sample is weighed into the thimble and the mouth of the thimble is plugged with defatted cotton wool, and inserted into the extraction unit.

The extraction cups were cleaned, dried, weighed and 80ml of petroleum ether were measured into each cups and the heating temperature adjusted to 135°C which is the extraction temperature for fat using petroleum ether as stated in the manual. The cups were set into the Soxtec unit with each cup aligning with its respective thimble. There are three stages involved; the boiling/extraction, rinsing and the drying. The extraction stage was for 30minutes in ‘boiling’ position and 30 min in ‘rinsing’ position after which it was aerated for 15 min. The cups were removed, cooled in a dessicator and weighed. Equation 8 was used for the calculation of crude fat.

$$Fat, (\%) = \frac{W3-W2}{W1} x100 \quad \textbf{(8)}$$

Weight of the cup with the extracted oil = W_3

Weight of the empty cup = W_2

Weight of sample = W_1

3.4.4 Determination of ash content

The ash content was determined using the method described by AOAC (2000). Crucibles were washed and dried in the laboratory hot air oven (Surgifriend Medicals, England. SM9053) maintained at 105^0C for 30 min. It was allowed to cool in a dessicator and weighed. 2.5 g of the samples were then weighed into the crucible and charred on a heater inside a fume cupboard to drive off most of the smoke. The samples were transferred into a pre-heated muffle furnace (Surgifriend Medicals, England. SM9080) maintained at 550^0C until a light grey ash was observed. The crucibles were transferred directly into a dessiccator, cooled and weighed immediately.The ash content was calculated using equation 9.

$$\text{Ash content,\%} = \frac{(\text{weight of crucible} + \text{ash}) - (\text{weight of empty crucible}}{\text{weight of sample}} \quad x \quad 100$$

(9)

3.4.5 Determination of crude fibre

Crude fibre was determined using the method described by AOAC (2000). Two grams of sample was weighed into 250 ml conical flask. 100 ml of 1.25 % H_2SO_4 was added and boiled under reflux for 30 min. The sample was filtered and completely rinsed with distilled water. The residue was transferred with spatula back into the conical flask, 100 ml of 1.25 % NaOH added and again boiled under reflux for another 30 min. The residue was filtered and rinsed thoroughly after which the residue was transferred into a crucible and dried in oven at 180 ^{0}C for 3 h, then cooled and weighed. The sample was returned to muffle furnace and ash for 2 h at 550 ^{0}C until completely ashed. It was cooled and weighed. The calculation of crude fibre was done using equation 10.

Crude fibre, (%) $= \frac{W2-W3}{W1}$**(10)**

W_1 = weight of the sample

W_2 = weight of the crucible + sample after oven drying

W_3 = weight of the crucible after ashing

3.4.6. Determination of carbohydrate

Carbohydrate was estimated by difference using equation 10:

Carbohydrate= [100 - %(moisture+ protein+ fat+ ash+ crudefibre) **(11)**

3.4.7. Determination of free fatty acid

The general titrimetric method for the determination of free fatty acid (FFA) as described by AOAC, (2000); Akinoso and Adeyanju,(2010) were used. The principle involvespreparation of a mixture of 25ml diethyl ether and 25ml alcohol and 1ml phenolphthalein solution (1 %), and carefully neutralised with 0.1 M sodium hydroxide. 1 g of oil sample was put in the mixed neutral solvent and titrated with aqueous 0.1 M sodium hydroxide with the warm solution shaken continuously until a pink colour which persists for 15 s is obtained. The FFA was calculated as oleic acid (1ml 0.1M sodium hydroxide equals 0.0282g oleic acid).

3.4.8 Determination of amylose content

Amylose content of the rice was estimated as described by Adeyemi, (2009). This involves digestion of 100mg of rice flour with 1ml of 95% ethanol and 9ml of 1N NaOH, the sample was heated for 10 min in a boiling water bath, and diluting the gelatinized starch with distilled water, 5ml of the starch solution was pipetted into a

100 ml volumetric flask, 1ml of 1N acetic acid and 2ml of iodine solution added, and made up to volume and absorbance was read at 620nm. Amylose content was determined by reference to a standard curve.

3.4.9 Estimation of metabolizable energy

The metabolizable energy of the rice and flakes were calculated from the three basal nutrients in the samples (protein, fat, and carbohydrate) using Atwater factor as described by FAO (2002). To calculate the ME, the percentage of fat, protein, and carbohydrate eelier estimated in the rice and flakes are then multiplied by their respective Atwater factors, added together, and multiplied by 10. Equation 12 was applied in the calculation of metabolizable energy

ME (kcal/kg) = 10 (3.82 x CP) + (8.37 x CF) + (4.16 x CHO) **(12)**

Where ME= Metabolizable energy

CP= % crude protein

CF=% crude fat

CHO= % carbohydrates

3.4.10 Determination of phytate

The method for evaluation of phytic acid was carried out as described by Garcia-Estepa *et al*., 1999. The ground samples (5.0±0.5 g) were extracted under magnetic agitation with 40.0 ml of extraction solution (10 g/100 g Na_2SO_4 in 0.4 mol/l HCl) for 3 h at room temperature. The suspension was centrifuged at 5000 rpm for 30 min and the supernatant was filtered using whatman no. 1. 10ml of supernatant (containing between 3.3 and 9.0 mg of phytic acid) waspipetted into a 100 ml centrifuge tube together with 10.0 ml of 0.4 mol/l HCl, 10.0 ml of 0.02 mol/l $FeCl_3$ and 10.0 ml of 20 g/100 g sulphosalicylic acid, shaked gently and the tube used was sealed with a rubber cork through which passes a narrow 30 cm long glass tube, to prevent evaporation.

The tube was placed in a boiling water bath for 15 min, and then allowed to cool. The sample was centrifuged at 5000 rpm for 10 min, decanted, filtered and the residue was washed several times with small volumes of distilled water. The supernatant and washed fractions were diluted (100.0 ml). One aliquot (20.0 ml) adjusted to pH 2.5.0.5 by addition of glycine was diluted to 200 ml. The solution was heated at 70 °C and, whilst still warm, titrated with 50 mmol/l EDTA solution. The 4:6 Fe/P atomic ratios was used to calculate phytate content.

3.5 Determination of mineral element

Mineral analysis Fe, Mg, Cu, Zn, Pb and Ca were conducted using Atomic Absorption Spectrophotometer (Buck 210). Dry digestion method was used in the preparation of the sample for mineral analysis. One gram of the dried samples was weighed into crucibles, charred in a fume cupboard and ashed in muffle furnace at 550ºC for 3h (AOAC, 2000). The ash was dissolve using 0.1M H_2SO_4 and filtered into a 100 ml volumetric flask and filled to the mark with deionised water. De-ionised water was used as a blank to zero the equipment for the analysis. Atomic Absorption Spectrophotometer Buck Scientific Model 210A with air/acetylene was used for the analysis of metals. Standards for each element under investigation was prepared in part per million (ppm) and the limit standard concentration for each element was adhered to according to the BUCK Scientific instruction.

The standard solutions were aspirated and the graph obtained. The samples concentrations of various metals were read and calculated using equation 13.

$$\text{Specific mineral (i.e Zn, Fe) ppm} = \frac{\text{Machine reading (ppm)}}{\text{Weight of sample}} \text{ x dilution factor}(100) \quad \mathbf{(13)}$$

3.6 Determination of cooking properties on rice

The cooking parameters that were estimated include the cooking time, elongation ratio, water uptake ratio and solid loss.

3.6.1 Cooking time

Rice was cooked in excess water. Twenty grains rice was cooked with a colander in boiler placed on an electric heater (100ºC) and timer for cooking time. The cooking time of the rice was recorded after complete absence of white chalk when the rice grain was pressed with spoon against the pot or rubbed in between the fingers (Danbaba *et al.*, 2011).

3.6.2 Water uptake ratio

Rice was cooked in excess water. Two grains rice was cooked with 20ml water in a 100 ml beaker placed on the electric cooker heater (Sareepuang *et al.*, 2008). Samples were removed at cooking time, weighed and calculated using equation 14:

$$Wateruptake(\%) = \frac{\text{weight of cooked rice}}{\text{weight of raw rice}} \quad \textbf{(14)}$$

3.6.3 Elongation ratio

Rice was cooked in excess water. Two grains rice was cooked with 20 ml water in a 100 ml beaker placed on an electric heater. Samples were removed at cooking time to measure with length and wide (before and after cooked) and calculated using equation 15 (Sareepuang *et al.*, 2008):

$$Elongationratio = \frac{\text{Length of cooked rice}}{\text{Length of raw rice}} \quad \textbf{(15)}$$

3.6.4 Solid loss

Rice was cooked in excess water. Two grains rice was cooked with 20 ml water in a 100 ml beaker placed on an electric heater. Twenty five ml sample of the cooked rice water (previously well agitated) was placed in a reweighed flask and air dried in an oven at 105ºC for 1 h. After that, the sample was fully dried at the same temperature until a constant weight in the presence of P_2O_5 desiccant. The amount of solids leached was calculated as kilogram of solids per kilogram of dry grain (Bello *et al.*, 2004).

3.7 Pasting properties

Pasting properties of rice flour were determined using the method as described by IITA (2001) laboratory manual.The rheological properties of 8% rice flour slurries (approximately 40g, corrected to 14% moisture, in 240 ml deionised water) were measured with a Newport Scientific Rapid Visco Analyser Model RVA-SUPER 3 with thermoclin for windows soft. (Brabender® OHG, Duisburg, Germany). The slurry was heated from 50 to 95ºC at a rate of 1.5ºC/ min, held at 95ºC for 15min, cooled to 50ºC at 1.5ºC/min and finally held at 50ºC for 15min. The following parameters were determined on RVA curve:

I. Peak viscosity (maximum viscosity during heating)
II. Hot paste viscosity (trough)
III. Cold paste or final viscosity (viscosity at end of cooling period)
IV. The breakdown was calculated as the difference between peak and trough viscosities.
V. The setback was calculated as the difference between the cold paste or final viscosity and the peak viscosity.
VI. Pasting temperature.
VII. Pasting time.

3.8. Volatile and non volatile compounds analyses

The volatile and non volatile compounds of rough, parboiled and cooked rice at optimum storage and processing conditions were analysed by Gas Chromatography Mass Spectrometry (GC-MS) as described by Wen-Chieh *et al.,* (2007). The samples were milled, sieved (60-mesh testing sieve), and 5 g of the samples were weighed into 100 ml flask. The volatileand non volatile compounds were extracted with dicloromethane (1:2) mixture by liquid-liquid extraction in separatory.This analysis was performed using a Shimadzu GCMS-QP2010s Gas Chromatograph/Mass-Spectrometer (GCMS) and an OI 4660 "Eclipse" Purge and Trap Concentrator with an OI 4551A autosampler.

These results were obtained using a 30m X 0.25mm X 1.4µ RTX-VMS fused silica capillary column (Restek Corporation). A temperature profile of 35-220°C was utilized, and the advanced flow control (AFC) was programmed to provide a constant linear velocity of 35cm/sec. A total analysis time of 12.5 minutes gives a GC cycle time that corresponds approximately to the cycle time of the purge and trap concentrator. The mass spectrometer was scanned in the full-scan mode from m/z 36 to 260 in 0.5sec scan intervals.The volatile components of unknown samples were identified by computer through searching and matching NIST and Weily MS libraries. The volatile components were quantified using peak area normalization. The detector (electron multiplier) was adjusted to give adequate response at the lowest calibration level and avoid saturation at the highest calibration level.

3.9. Analysis on flakes

The two major analyses carried out on flakes were proximate composition (protein, moisture, fat, ash and carbohydrate), metabolisable energy, antinutritional content (phytate), andwater absorption as a functional parameter.

3.9.1. Chemical quality of rice flakes

Moisture, crude protein, ether extract, ash, carbohydrates, metabolizable energy and phytate were carried out as discussed in the analysis of rice with the same methodology and reagents.

3.9.2 Water absorption capacity

Water absorption capacity of *Ofada* rice flakes was measured by weighing the water uptake of flakes at room temperature for 15 min. A Sample of 2 g of flakes was weighed into the centrifuge tubes with 10 ml of distilled water. These were allowed to stay for 15 min, followed by centrifugation at 400 rpm for 15 min. The excess water was decanted and the values of absorbed water were expressed as g per 100g of flake (Lu and Walker, 1988).

3.10. Data analysis

Data from each analysis were subjected to analysis of variance at test of significance 5%, regression analysis and lack of fit test at 5%. This was followed by the optimisation of the processing parameters for the best production of *Ofada* rice and its flakes.

3.11. Modelling and optimisation

Response surface methodology was applied to the experimental data using commercial statistical package (Design expert, 7.0, Stat Ease Inc., Minneapolis) for the generation of response surface plots and modelling equations for each of the response estimated. Optimisation was conducted on experimental data on physical, chemical, cooking and pasting properties of rice and functional and chemical quality of flakes followed by combined optimisation process for all the parameters analysed. Optimisation of the process variables was based on the selection of the indicator that best determined the product quality acceptability.

3.12 Sensory evaluation on rice flakes

Sensory attributes: colour, crispiness, taste, aroma, and overall acceptability based on a nine point hedonic scale, where 1 is dislike extremely and 9 is like extremely was assessed. The result was subjected to statistical analysis.

3.13Sorption isotherm characteristics of *Ofada* flakes

The moisture isotherm of the flakes with best characteristic indices as generated by optimisation process was studied using static equilibrium method as described by Alam and Singh(2011).Hot air oven was used as temperature control chamber and the dessicators as humidity control chamber. The desired level of humidity was controlled through preliminary study on appropriate concentrations of aqueous glycerol solution for attaining a particular relative humidity in the dessicator with experimental tabulated data recorded by Alam and Singh (2011) as guide. The relative humidity and temperature were monitored with the help of digital thermo-hygrometer (Brannan, England).

Experiments were conducted to standardise the concentrations of glycerol to relative humidity (40, 60, 70, 80, and 90%) at 25, 35 and 45^{o}C (Table 3.3). Glycerol of desired concentration was transferred into the dessicators, covered and kept at control temperature for 12h to allow the glycerol to saturate the dessicator. For adsorption, the sample was dried to 1.4% (d.b) and 5g taken in petri dish. This was placed over the wire mesh in the dessicator, covered and then transferred into the oven set at 25, 35 and 45^{o}C respectively. The weight of the sample was noted periodically until the change in weight reached a constant value presumed to be equilibrium moisture content (EMC).

Non linear regression module of Statistical Package for Social Sciences, (SPSS version 17.0 was used for analysis of the good fitness of the models. The modelsinclude Guggenheim Anderson De-Boer (GAB), Oswin, Brunauer Emmett and Teller (BET), and Halsey. The goodness of fit of the models were evaluated using root meansquare error (RMSE), percentage deviation (%E), and coefficient of determination (R^2).

Table 3.3: Experimental values of glycerol concentrations for different relative humidity at different temperatures

	Glycerol concentrations (%) Temperature (^{0}C)		
RH (%)	25 ^{o}C	35 ^{o}C	45 ^{o}C
20	96.3	93.7	94
40	88.5	84.5	85.6
60	74.7	71.6	71.8
70	62.8	64.4	65.1
80	48.1	53.5	54.7
90	29.3	32.7	33.2

RH-relative humidity

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical characteristics of *Ofada* rice

The effect of processing condition on physical characteristics of *Ofada* rice (length, width, breadth, thousand weight, head rice yield, brokenness, chalkiness, lightness and colour value) of *Ofada*were shown in Table 4.1.

4.1.1. Size characteristics of *Ofada* rice

The size characteristics (length, width and breadth) of *Ofada* rice as affected by the processing parameters were presented (Table 4.1). There existed significant differences at $p<0.05$ in sizes of the *Ofada* rice after treatments which revealed how effective processing conditions can affect quality of rice.

4.1.1. 1. Length

The length of rice were significantly affected ($p<0.05$) by the processing conditions of the paddy. The maximum and minimum values obtained were 6.29 and 5.53 mm respectively with an average value of 5.88 mm. The maximum value was obtained from the rice stored for 1 month and processed by soaking for 5 days, parboiled at 120°C, and dried at 50°C while the minimum value was as a result of storage of paddy for 1 month, soaked for 1 day, parboiled at 80°C, and dried at 70°C. The result revealed that the lack of fit was significant which is not good enough for the model. The R^2, adjusted R^2, predicted R^2, and adjusted precision values for the length characteristics of *Ofada* rice were shown (Table 4.2). High multiple correlation coefficient ($R^{2)}$, low standard deviation and predicted residual sum of square identify the best model. However, low standard deviation and predicted residual sum of square(PRESS) values of 0.12 and 0.45 respectively indicated that the model may still be relevant. The coefficient of the model is presented (Table 4.3).

The response surface graphs showing the effect of processing conditions on the elongation of *Ofada* rice were presented (Figs. 4.1 - 4.6). Observations from the figures revealed that steady increase in soaking time and parboiling temperatures favoured elongation of the processed *Ofada* rice. The positive coefficient of soaking time and parboiling temperature as shown in Table 4.3 supported this. The response surface plots shown inward concave curves for the effect of drying temperatures with the mid temperature 50°C producing the highest increase (Figs. 4.3, 4.4, 4.6) while storage effects curves were concave inward.

According to Kurien *et al.*, (1964) as reported by Roy *et al.*, (2011), parboiling contributes to the expansion ratio of rice. This could be due to water absorption capacities of the rice varieties and the parboiling process. An investigation into the effect of parboiling on physico-chemical qualities of two local rice varieties in Nigeria by Otegbayo *et al.* (2001) revealed that parboiled rice kernel has a short length and broader breadth when compared with the non parboiled rice sample. The dimension of parboiled rice could be influenced by the amylose content of the rice (Roy *et al.*, 2011). Otegbayo *et al.* (2001) recorded length and breadth range of 6.66 - 7.04 mm and 2.91- 3.0 mm respectively.

The consumers judge the quality of rice on the basis of size and shape of rice grain. The preference for grain size and shape can vary from one group of consumer to another group of consumers (Roy *et al.*, 2011). It is generally noted that consumers usually preferred long grain rice compare to short rice. The grain length, weight and width determine the physical quality of rice grain. The classification of rice is based on length such as short, medium and long grain. *Ofada* rice is believed to be short grain rice but the influence of certain processing conditions could reclassify it to medium or long grain rice (Adu-Kwarteng *et al.*, 2003).

The shape (ratio of length/width) influences the prices of rice in different countries survey by Laurian (1986). Long rice is usually favoured in term of price compare to intermediate or short grain rice. The average shape characteristic (length/width) of rice samples from Philippines, Indonesia and Thailand were given at 3.2, 2.5 and 3.5 mm respectively (Laurian, 1986). The result of the experiment is against the report of Juliano and Duff (1989), which claimed that processing method did not affect the size of rice but the varietal factors.

4.1.1.2 Width

Width is another renounced part of size characteristics of the rice. Length – width ratio is a very stable varietal property for determining grain size and shape. The minimum value of 2.50 mm was recorded when the paddy was stored for 5 months, soaked for 5 days, parboiled at 120 ^{0}C, dried at 30 ^{0}C while the maximum value of 3.03 mm was recorded from paddy stored for one (1) month, soaked for 1 day, parboiled at 120 ^{0}C, and dried at 30 ^{0}C dried.

There were significant differences ($p<0.05$) in rice width in relation to the treatments. The mean width value of *Ofada* rice was 2.80 mm and the lack of fit was not significant which was also good for the model. The low standard deviation and PRESS values of 0.084 and 1.73 respectively demonstrated that the model was more reliable. The R^2, adjusted R^2, predicted R^2, and adjusted precision values for the length characteristics of *Ofada* rice were shown (Table 4.2). Negative predicted R^2 (-3.3437) revealed that mean is the best descriptor of the effect of processing conditions and storage duration on rice width. The quadratic coefficient of the model showing the effect of processing conditions (soaking, parboiling, drying, and storage) and their interactions on rice width were shown (Table 4.3).

Table 4.1: Physical properties of *Ofada* rice

Run	Soaking day	Parboiling °C	Drying °C	Storage Month	Length mm	Width mm	Breadth mm	HRY %	Brokenness %	Chalkiness %	Lightness %	Colour value
1	1	120	70	1	6.28	2.86	2.08	72.98	24.95	0	66	702.45
2	1	80	70	1	5.54	2.92	2.18	50.74	83.08	47.18	69.59	1887.19
3	5	80	30	5	5.55	2.84	1.98	71.25	33.81	1.91	71.26	1859.97
4	5	80	30	1	5.7	2.82	2.12	58.63	68.08	42.37	74.09	1846.93
5	3	80	30	9	5.87	2.83	1.97	64	3.72	0	72.55	3888.24
6	5	80	50	5	5.72	2.9	2	58	18.65	36.42	74.82	1975.67
7	1	120	30	5	6.01	2.5	2.18	65.25	2.17	0	75.08	2014.02
8	5	80	70	1	5.53	2.94	2.17	52.61	71.92	49.64	69.56	1868.81
9	3	120	70	9	6.13	2.7	2.03	65.25	3.93	0	66.97	2002.6
10	3	120	50	5	5.94	2.82	2.04	70	9.06	1.04	78.8	1947.36
11	5	120	30	9	6.04	2.67	2.1	70.75	0.81	0	71.04	2106.4
12	1	100	50	5	5.72	2.92	2.02	75.5	16.75	1.79	74.74	2021.72
13	3	120	70	5	5.81	3.02	1.98	65.5	45.93	0.18	77.33	1967.56
14	1	100	50	9	5.87	2.7	2.18	74.25	2.71	0	69.02	1964.7
15	5	120	50	9	6.17	2.67	1.93	74.75	19.3	0	70.75	2013.56
16	1	120	70	1	6.29	2.88	2.15	67.48	19.34	0	70	560.81
17	3	100	50	5	5.88	2.88	2.06	72.5	20.67	1.18	77.96	2006.34
18	5	100	50	5	5.94	2.96	2.08	70.96	6.61	1.62	71.06	1986.27
19	1	80	30	1	5.73	2.83	2.11	53.8	55.57	43.31	74.03	1850.32
20	1	120	30	1	5.97	3.03	2.34	69.88	2.83	0	77.37	1817.13
21	5	100	30	9	5.73	2.8	2.16	76.5	4.76	3.78	67.91	1992.57
22	1	80	70	5	5.96	2.84	2.08	54.75	70.81	33.21	77.25	2078.07
23	5	80	70	9	5.77	2.93	1.93	60.25	51.35	0.42	71.16	2103.06
24	1	80	30	9	5.9	2.67	2.03	70.25	57.69	44.35	73.72	2078.07
25	1	120	30	1	6.02	3.02	2.36	76.45	2.88	0	77.49	1738.57

Table 4.2: ANOVA of regression of physical properties as a function of storage and processing conditions

Parameters	p-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Length (mm)	0.0051	0.8852	0.7244	-0.4408	8.348
Width (mm)	0.0303	0.8243	0.5782	-3.3437	6.699
Breadth (mm)	0.0015	0.9131	0.7915	-1.0044	10.887
HRY (%)	0.0013	0.9148	0.7956	-0.1564	9.976
Brokenness(%)	0.0053	0.884	0.7217	0.1441	7.257
Chalkiness (%)	0.0174	0.8467	0.632	-0.5108	5.933
Lightness	0.0082	0.8716	0.6919	-0.4182	6.907
Colour value	0.0909	0.7658	0.4379	-0.1151	7.152

Table 4.3: Coefficient of the model on effect of storage and processing parameters on physical qualities of *Ofada* rice

	Length mm	**Width mm**	**Breath mm**	**HRY[5] (%)**	**TGW (%)**	**Brokenness (%)**	**Chalkiness (%)**	**Lightness**	**Colour Value**
Intercept	6.47	1.01	-0.77	-70.72	188.87	280.32	229.71	69.6	119.01
S	0.03	0.18	0.06	-8.38	22.46	12.82	16.16	95	215.57
P	-0.04	0.05	0.07	2.5	-0.42	-4.33	-4.33	-0.41	3.01
D	0.03	-0.02	-0.011	0.51	2.37	-1.32	1.37	0.41	18.87
T	0.05	0.03	-0.08	3.8	0.53	-5.05	-13.39	3.04	31.88
S^2	$7.73x10^{-3}$	-0.02	-0.01	0.69	-2.89	2.34	-0.38	0.18	31.36
P^2	$2.91x10^{-4}$	$-2.13x10^{-4}$	$-2.9x10^{-4}$	-0.01	$3.22x10^{-3}$	0.02	0.02	$3.87x10^{-3}$	0.03
D^2	$-2.53x10^{-4}$	$1.63x10^{-4}$	$2.03x10^{-4}$	-0.01	-0.02	0.03	$-3.69x10^{-3}$	$1.83x10^{-3}$	-0.03
T^2	$5.46x10^{-3}$	$-7.26x10^{-4}$	$4.32x10^{-3}$	0.06	0.62	-0.21	0.3	-0.27	-8.33
-SP	$-7.59x10^{-4}$	$-1.24x10^{-3}$	$-1.79x10^{-4}$	0.01	-0.01	-0.19	-0.12	-0.05	-3.61
SD	$1.29x10^{-3}$	$1.99x10^{-4}$	$3.83x10^{-4}$	0.05	-0.1	-0.13	-0.03	-0.02	-3.94
ST	$-4.57x10^{-3}$	$2.53x10^{-3}$	$4.24x10^{-3}$	-0.02	-0.18	-0.51	0.27	0.05	31.69
PD	$-6.05x10^{-5}$	$7.15x10^{-5}$	$-1.19x10^{-4}$	$3.99x10^{-3}$	$6.50x10^{-4}$	$3.22x10^{-3}$	$-5.38x10^{-3}$	$-2.89x10^{-3}$	-0.11
-PT	$-7.11x10^{-4}$	$-6.9x10^{-4}$	$-4.64x10^{-4}$	-0.03	-0.01	0.09	0.1	-0.01	0.31
-DT	$-2.20x10^{-4}$	$3.46x10^{-4}$	$1.18x10^{-4}$	-0.01	-0.1	-0.04	-0.05	$9.76x10^{-3}$	0.28

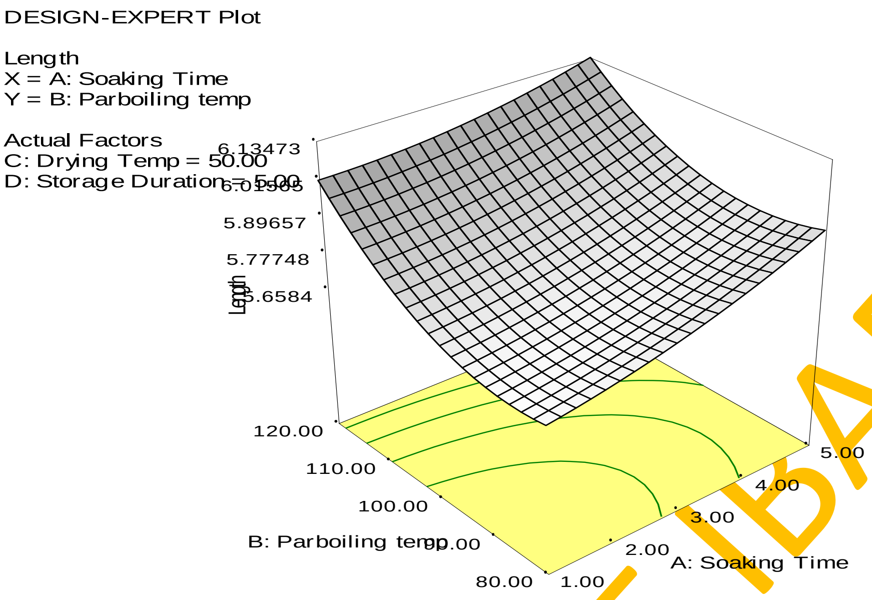

Fig. 4.1: Effect of soaking time and parboiling temperature on rice length

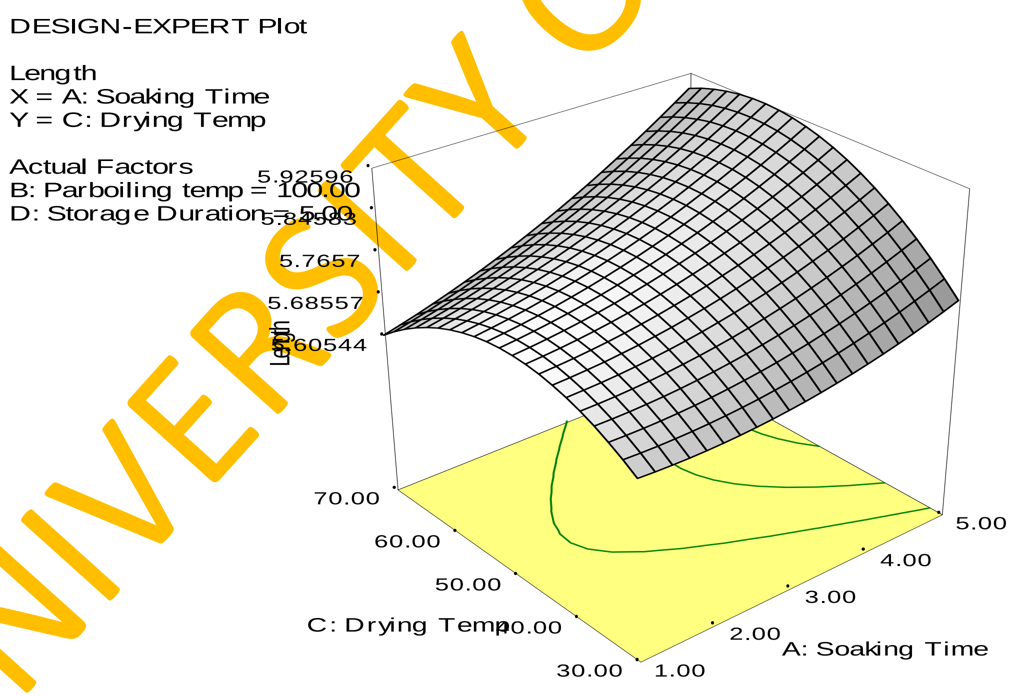

Fig.4.2: Effect of drying temperature and soaking time on rice length

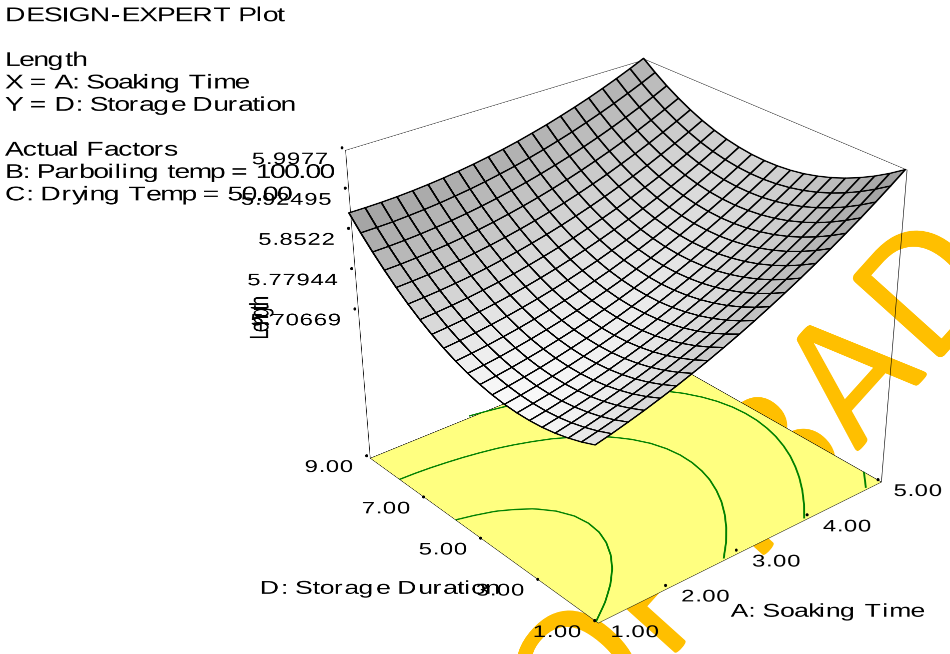

Fig.4.3: Effect of soaking time and storage duration on rice length

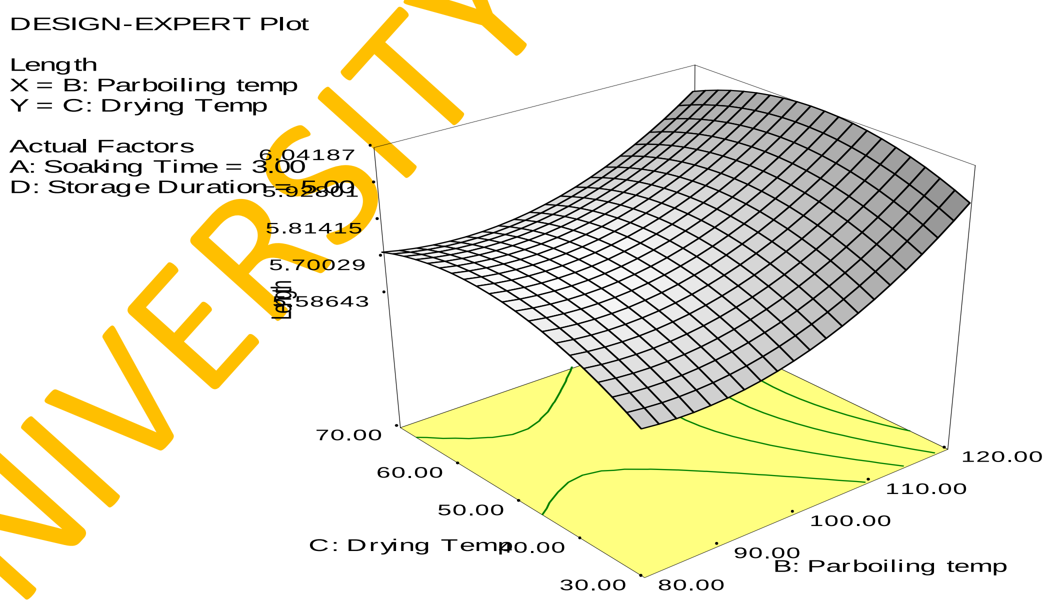

Fig. 4.4: Effect of parboiling and drying temperature on rice length

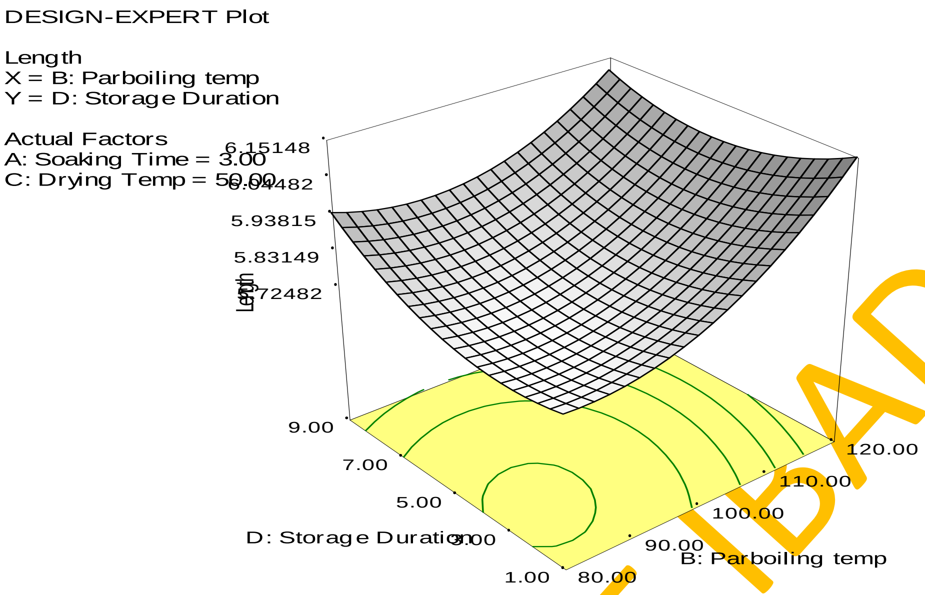

Fig. 4.5: Effect of parboiling temperature and storage duration on rice length

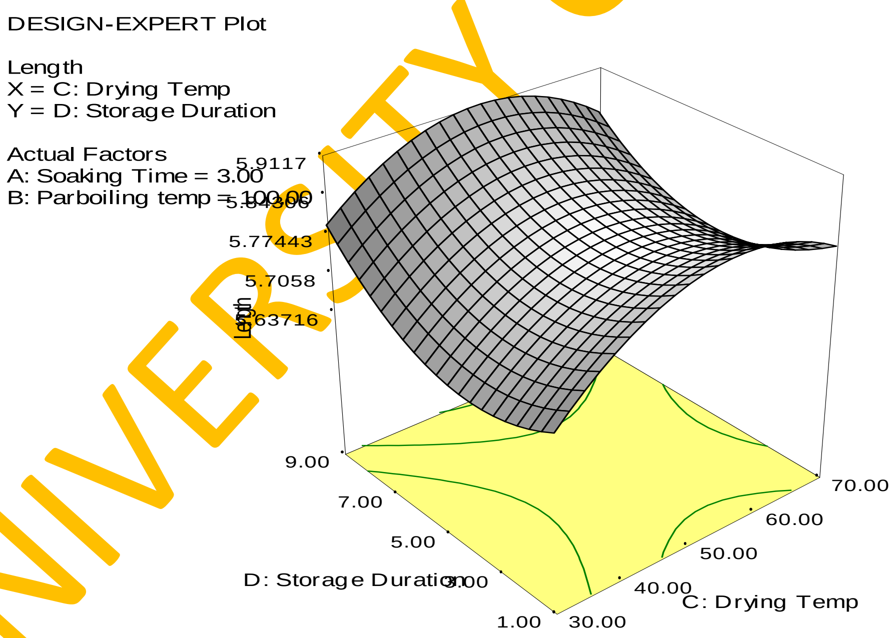

Fig.4.6: Effect of drying temperature and storage on rice length

The response surface plots, showing the interaction effect of soaking time and parboiling temperature, soaking time and drying temperature, soaking time and storage duration, parboiling and drying temperatures, parboiling temperature and storage duration, drying temperature and storage duration on the width of *Ofada* rice were presented (Figs. 4.7 – 4.12). The effect of soaking time and parboiling temperature were concave inward with mid soaking time favouring the highest increase while the extremes shown least effects (Figs. 4.7, 4.8,4.9, 4.10, 4.11). *Ofada* rice width increased with drying temperature (Figs. 4.8, 4.10, and 4.12) and decreased with increase in storage duration (Figs. 4.9, 4.11 and 4.12).

According to Danbaba *et al.*, (2012), the ratio of length to width is used for the determination of rice shape. Danbaba *et al.*, (2012) and Otegbayo *et al.*, (2001) recorded ranges of 2.61-3.2mm and 2.53-3.0 mm for rice width respectively. The variation might be attached to the varietal factors, processing conditions, climatic and geographical area of the rice origin. From the result, it was observed that the samples with high elongation were low in width. Rhaghavendra and Juliano (1970) recorded that parboiled rice expanded more in width and breadth than the length but however, the consumer preference to rice acceptability revealed long rice with less width.

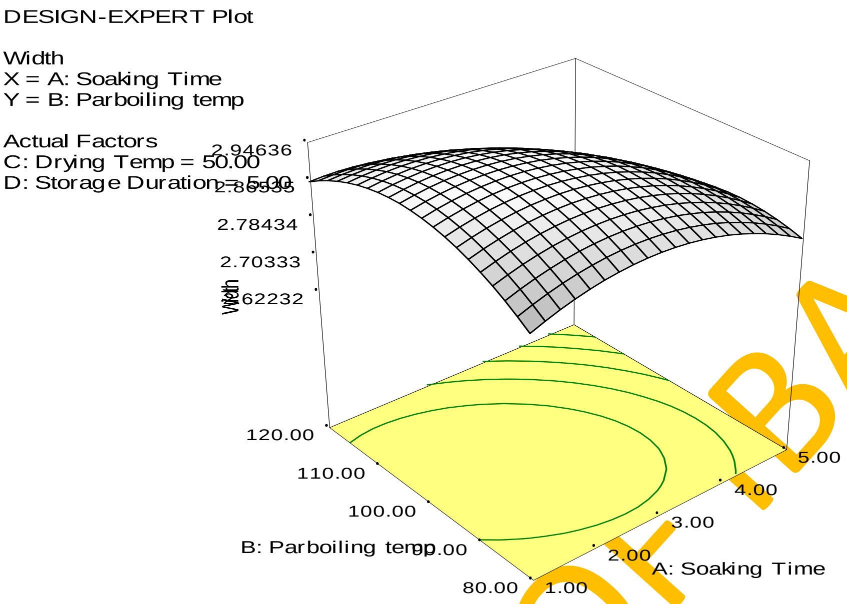

Fig.4.7: Effect of soaking time and parboiling temperature on width of rice

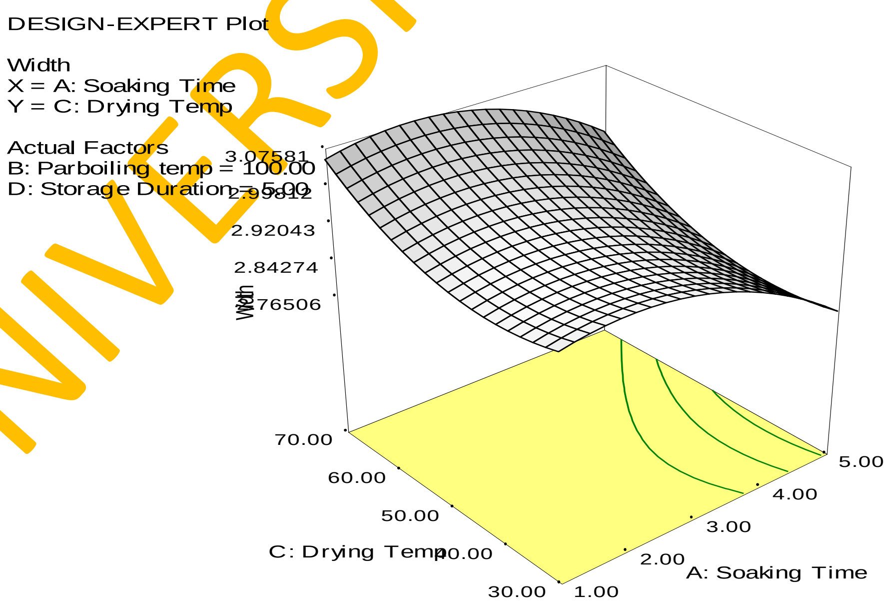

Fig.4.8: Effect of soaking time and drying temperature on width of rice

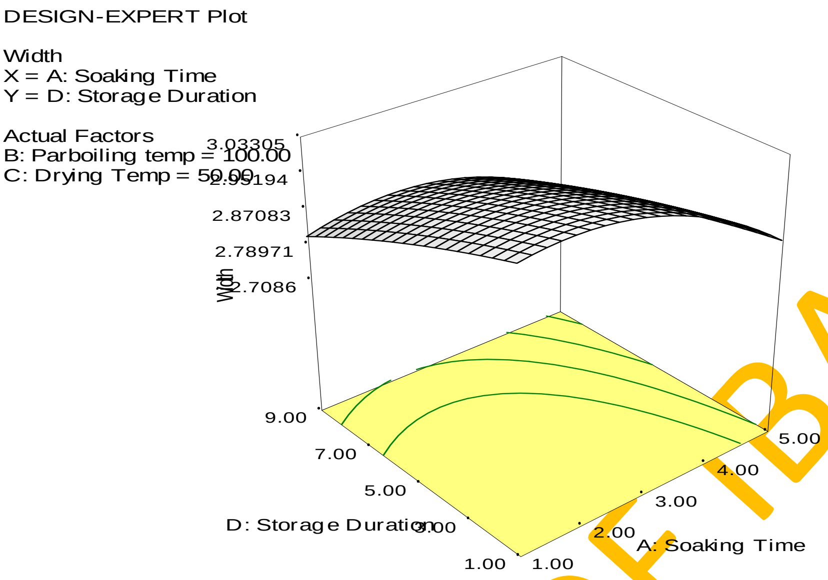

Fig.4.9: Effect of soaking time and storage duration on width of rice

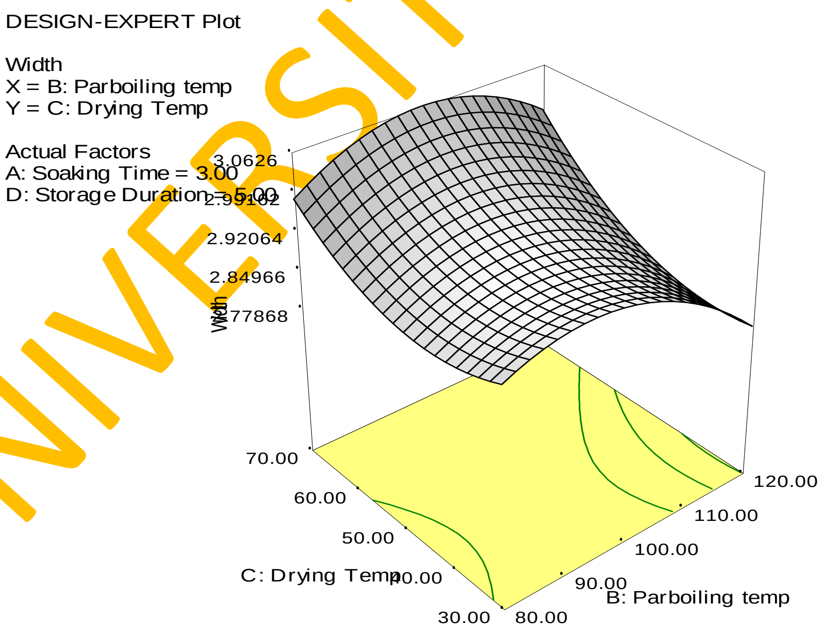

Fig.4.10: Effect of parboiling and drying temperature on width of rice

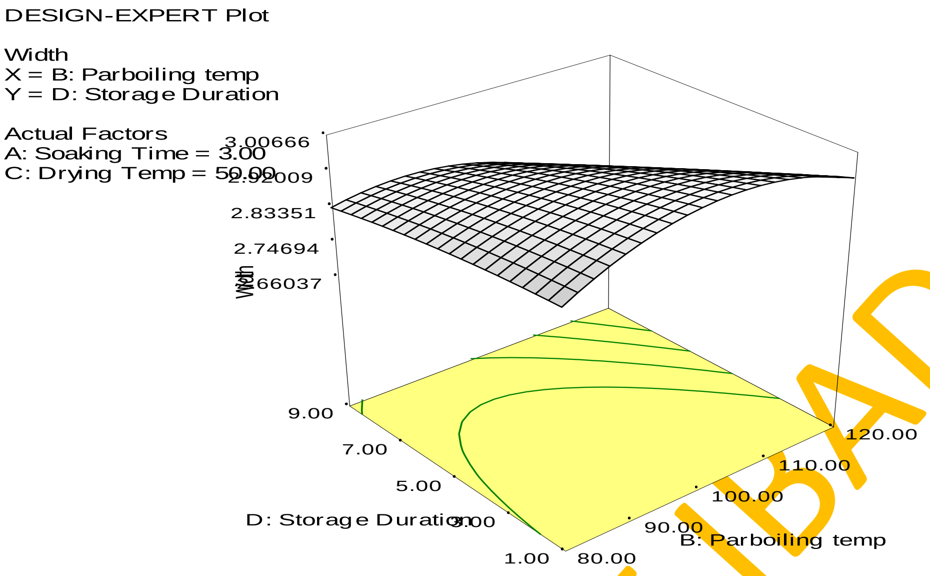

Fig. 4.11: Effect of parboiling temperature and storage duration on width of rice

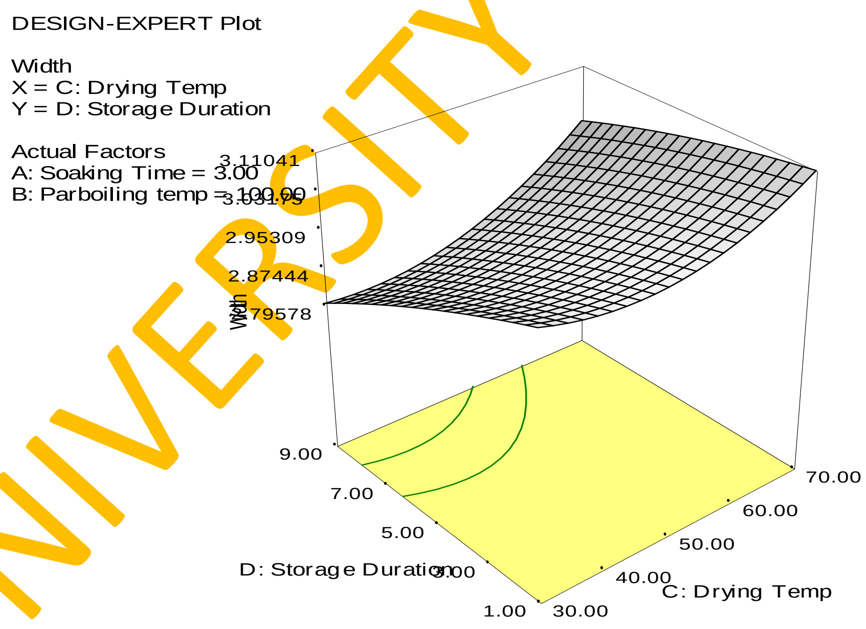

Fig.4.12: Effect of drying temperature and storage duration on width of rice

4.1.1.3 Breadth

The result obtained for the breadth ranged between 2.36 to 1.93 mm. The minimum breadth value was obtained at 9 month of paddy storage, one day soaking duration, 120^0C parboiling temperature, and 50^0C drying temperature while maximum value was recorded at1 (one) month paddy storage duration, 1 day soaking, 120^0C parboiling temperature, and 30^0C drying temperature. There existed significant differences (P<0.05) in the breadth of processed *Ofada* rice as a result of processing conditions. The non significance of the lack of fit was an indication that the model was fit. Low standard deviation and PRESS values of 0.050 and 0.58 respectively were also recorded which also supported model fitness. The coefficient of the model is presented in Table 4.3. Positive coefficients of soaking time and parboiling temperature revealed that the effect of these operation units brought increase on breadth of rice.

Breadth is also an important size characteristic of grain but is not involved in the estimation of the shape which is the important consumer index that determine the price and purchase of rice. Response surface graphs on the effect of interactions of soaking time and parboiling temperature, soaking time and drying temperature, soaking time and storage duration, parboiling and drying temperatures, storage duration and drying temperature, and parboiling temperature and storage duration on breadth of *Ofada* rice were shown (Figs. 4.13-4.18).

From the response surface graphs, the range of minimum to maximum values recorded for the effects of soaking time and parboiling temperature, soaking time and drying temperature, soaking time and storage duration, parboiling temperature and drying temperature, parboiling temperature and storage duration, and drying temperature and storage duration were 1.9124 - 2.12287 mm, 2.05677 - 2.23041 mm, 2.013 - 2.27632 mm, 1.97695 - 2.24219 mm, 1.95524 – 2.27516 mm, and 2.09452 - 2.39189 mm (Figs. 4.13 - 4.18) respectively. The effect of parboiling and storage duration produced the least breadth (Fig. 4.17). Parboiling and soaking showed relative inward concave curves, however, the curves in parboiling were more extended to a point before a steep downward curve (Figs. 4.13 and 4.16). Drying temperature and storage duration axis were concave outward.

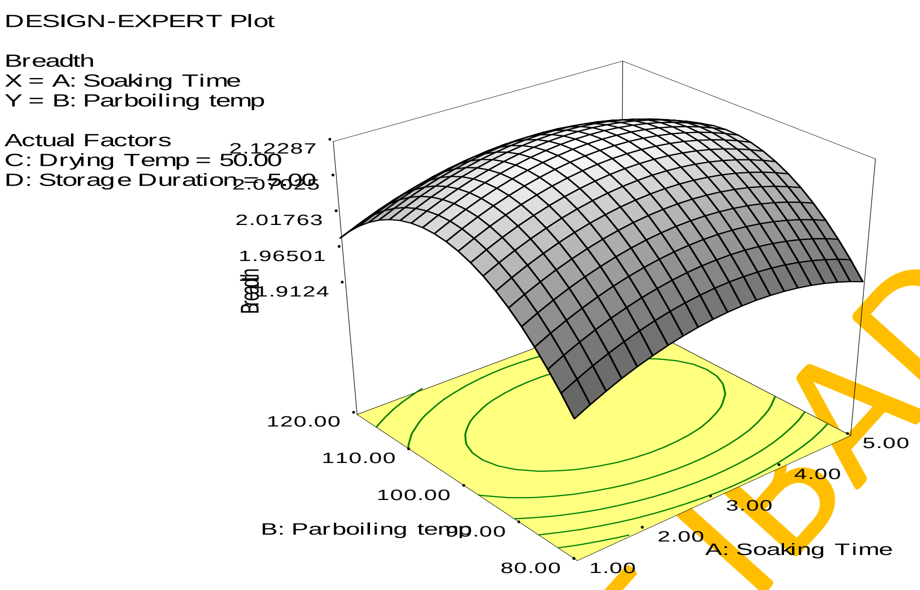

Fig.4.13: Effect of soaking time and parboiling temperature on rice breadth

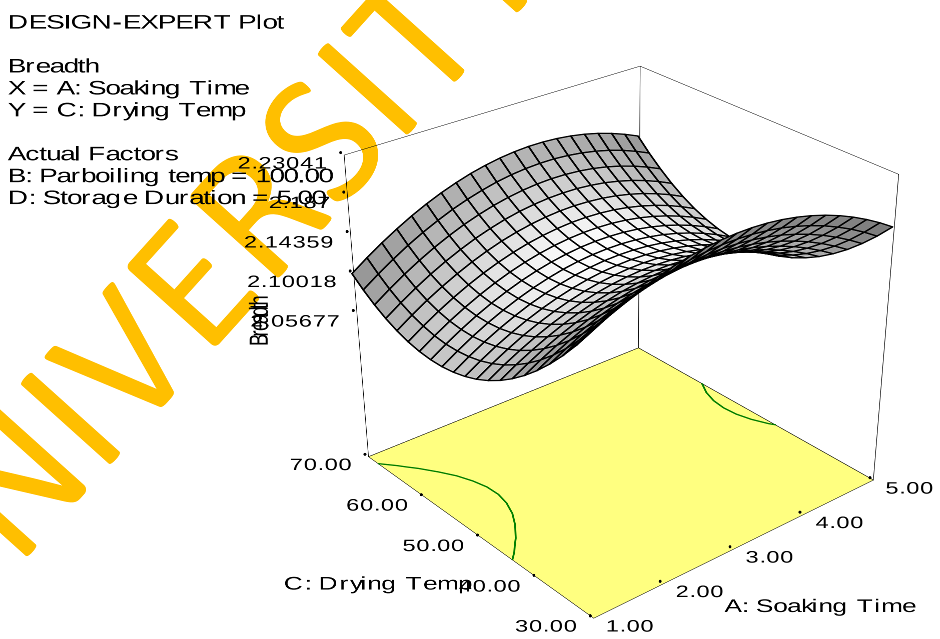

Fig.4.14: Effect of soaking time and drying temperature on rice breadth

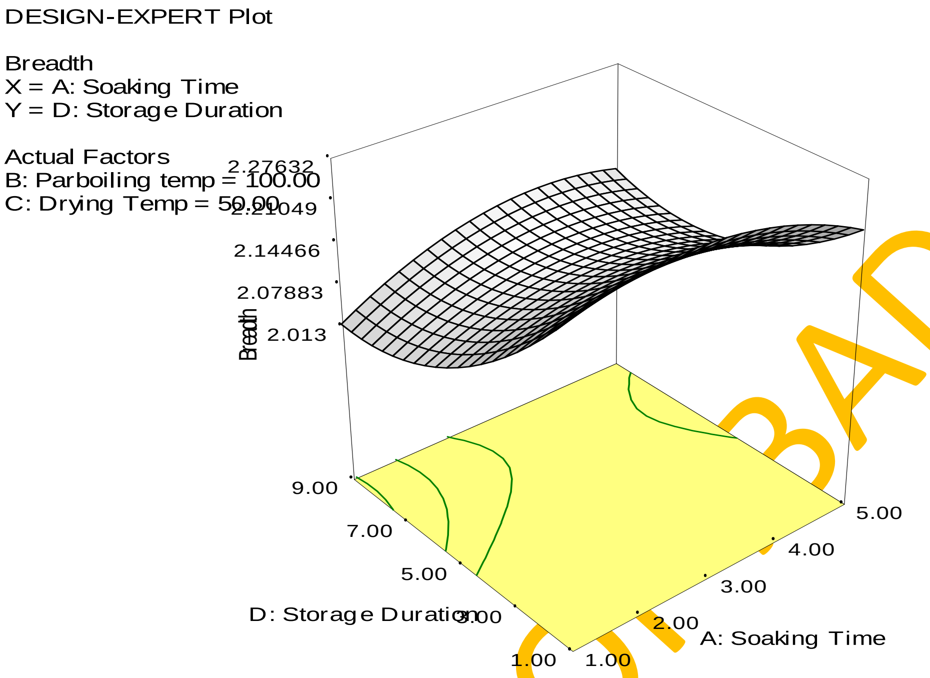

Fig. 4.15: Effect of soaking time and storage duration on rice breadth

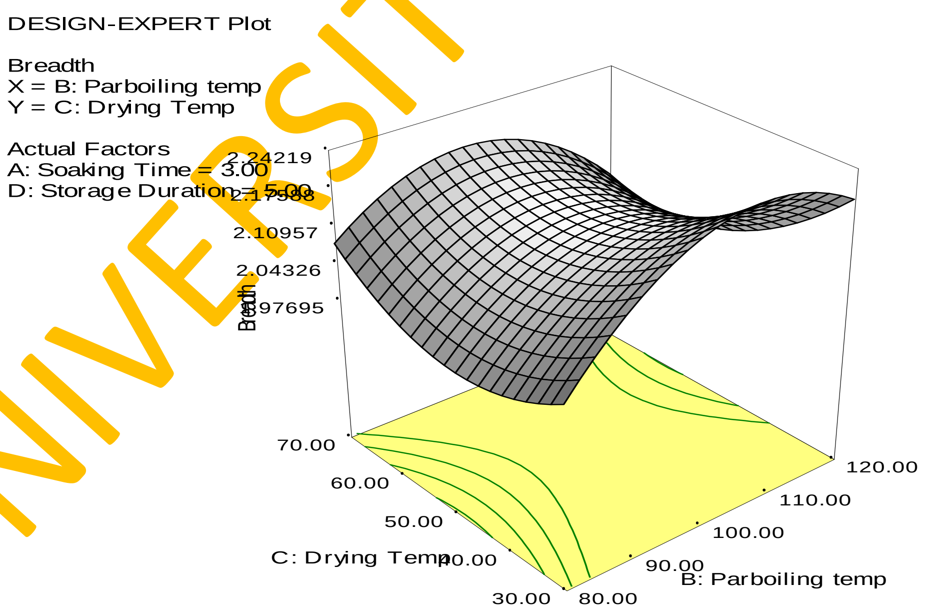

Fig.4.16: Effect of parboiling and drying temperature on rice breadth

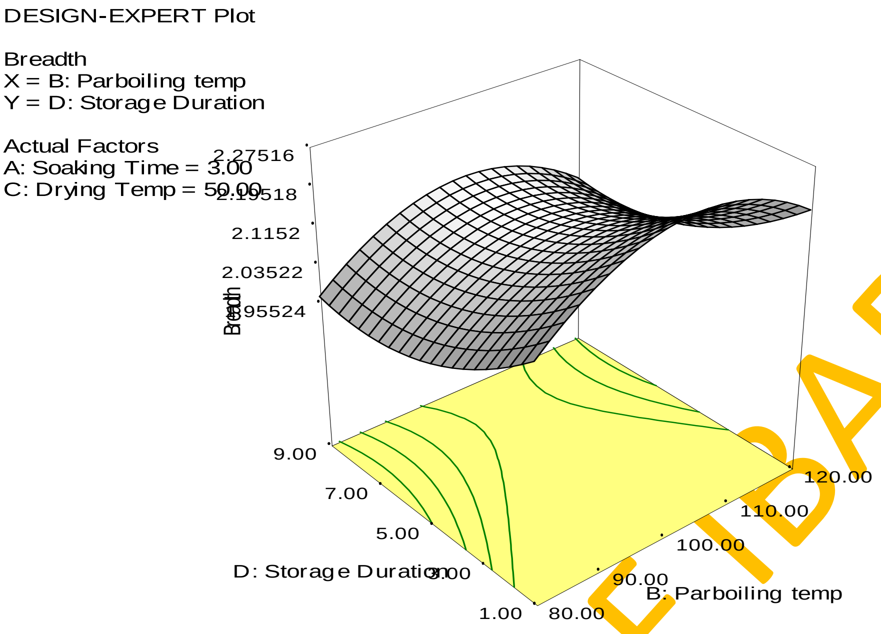

Fig. 4.17: Effect of parboiling temperature and storage duration on rice breadth

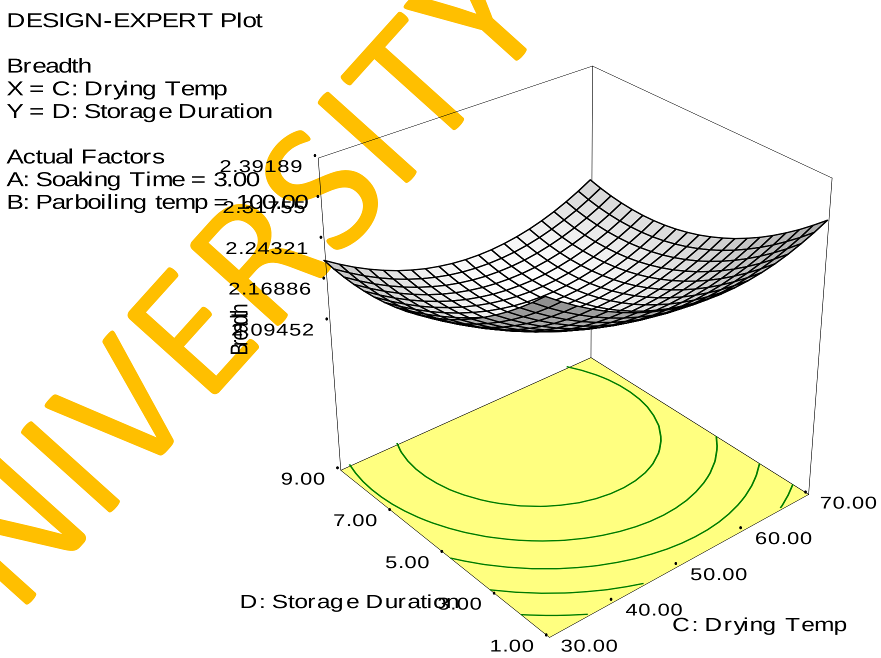

Fig.4.18: Effect of drying temperature and storage duration on rice breadth

4.1.2. Head rice yield (HRY)

The result of percentage HRY ranged from 50.74 to 76.50%. The minimum value 50.74 % was recorded when paddy was stored for 1 month, soaked for 1 day, parboiled at 80^{0}C, and dried at 70^{0}C while the maximum value 76.45 % was obtained from paddy processed by storage for 1 month duration, soaked for 1 day, parboiled at 120^{0}C, and dried at 30^{0}C.There were significant differences ($P < 0.05$) in the result obtained for HRY. The model for the result lack of fit was not significant which was good for the model and the model F-value of 7.67 implied the model was significant. The mean value of HRY was 66.49% while the R^2, adjusted R^2, predicted R^2, and adjusted precision values for the model of HRY were shown (Table 4.2). Standard deviation was 3.59 and the coefficient of the model on HRY as affected by processing parameters and storage is presented (Table 4.3);

The range of HRY (50.74 - 76.50 %) is related to the result obtained by Patindol *et al., (2008),* 59.6 - 89.4 % for certain cultivars of rice (Bilivar, Cheniere, Dixebelle and Wells). The result of the coefficient of model (Table 4.3) showed the effectiveness of parboiling temperature (P) and storage duration (T) at increasing HRY compared to other unit operations involved. According to Marshall et al., (1993) the effect of parboiling temperature and cultivar were discovered as the reason behind the variation in HRY of rice. Well parboiled rice is harder and gives a higher yield of head rice upon milling andincomplete parboiling causes increased kernel breakage upon milling (Marshall *et al., 1993*).

During parboiling, profound changes occurred in physical, chemical and functional properties of rice. Starch granules undergo irreversible swelling and fusion as a result of gelatinization (Patindol *et al., 2008*). Research has shown that rough rice storage history can affect head rice yield and cooking quality of rice (Hamaker *et al.*, 1993; Tamaki *et al.*, 1993; Chrastil, 1990). Changes during storage include increase in grain hardness and these changes occur most rapidly in the first months of storage (Daniels *et al., 1998*). This might be responsible for the high variation obtained in %

HRY in the paddy stored for 1 month. High coefficient of storage duration (T) supported this.However, parboiling of rough rice at high temperature and the long steaming time mayproduce dark colour and harder product, hence these products fetch lower price in the market (Kimural *et al.,* 1993; Bhattacharya, 1985).

There is relationship between head rice yield and soaking time of brown rice at different steaming time. Bhonsle and Sellappan (2010), also recorded HR recovery ranged from 45 – 74 % in the evaluation of grain quality of traditionally cultivated rice varieties of GOA, it was also reported that the quality rice variety should have HRY value of at least 70 %. HRY value depends on the grain type, chalking, cultivation practices and drying condition (Dipti *et al.*, 2003). The Response surface graphs for the effects of parboiling temperature and soaking time, soaking time and drying temperature, soaking time and storage duration, parboiling and drying temperatures, parboiling temperature and storage duration, drying temperature and storage duration on head rice yield of parboiled *Ofada* rice were presented (Figs. 4.19 – 4.24).

Illustration from the response surface graphs above revealed effects of soaking time and parboiling temperature, soaking time and drying temperature, soaking time and storage duration, parboiling and drying temperatures, parboiling temperature and storage duration, and storage duration and drying temperature on head rice yield of *Ofada* rice and the minimum and maximum values highlighted by the graph preferences were 60.1662 - 74.2208 %, 62.3937 - 76.0548 %, 68.75 - 76.3574 %, 51.8463 - 71.8169 %, 56.9201 - 72.6891 %, and 62.1518 - 74.4918 % respectively (Figs.4.19 – 4.24). However, from the results given above, soaking time and storage duration as shown in Figure 4.21 was more effective in maximising the head rice yield. Steady increase in parboiling temperature increases the HRY of *Ofada* rice to a point where further increase in parboiling temperature gives a tendency of decline in HRY.

4.1.3 Thousand Grain Weight

The values for the thousand grain weight (TGW) ranged from 240.80 to 292.20 g with average mean value of 262.04 g. However, a negative “Predicted R^2” implied that the overall mean is a best predictor of TGW than the current model. The results of TGW were not significant ($p > 0.05$) with the treatment. The model coefficient for the effect of processing parameters and storage on TGW of rice is presented in Table 4.3.

TGW is used as an indication of the presence of foreign materials and also to identify breeds since a particular breed of rice has its TGW range. According to Gayin *et al.*, (2009), the acceptable range for the TGW of paddy was 20 to 30 g. Values below 20 g indicate presence of immature, damage or unfilled grains(Adu-Kwarteng *et al.*, 2003). However, unprocessed paddy was referred to in the experiment not parboiled rice. The high value obtained in the experiment might be as a result of processing operations the *Ofada* rice was subjected such as soaking, that causes absorption and swelling, coupled with parboiling that lead to the gelatinization of starch with irreversible swelling and formation of hydrate with starch.

An important component of yield in rice is TGW, according to Liu *et al.*, (2009), TGW is determined by grain length, grain width and grain thickness. Grain thickness is regarded as the strongest determinant of TGW (Liu *et al.*, 2009). In most cases, the thousand grains could not be of a specific value but range. Several factors could determine the thousand grain weight of rice such as the variety, climatic condition and agricultural practices.

The thousand grain weight of cereals is usually done to determine likely presence of contaminants and maturity of the variety. It usually falls within a range for particular varietal specie of produce. Therefore, the range obtained from the experiment 292.20 – 240.80 g can be used as the basis for the TGW standardisation of the species of *Ofada* rice undergoing similar processing operations and storage.

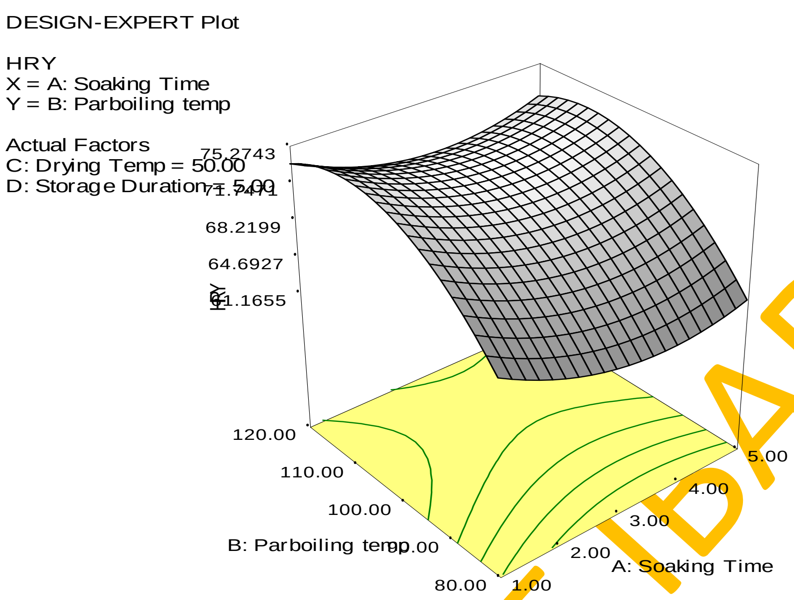

Fig.4.19: Effect of soaking time and parboiling temperature on HRY

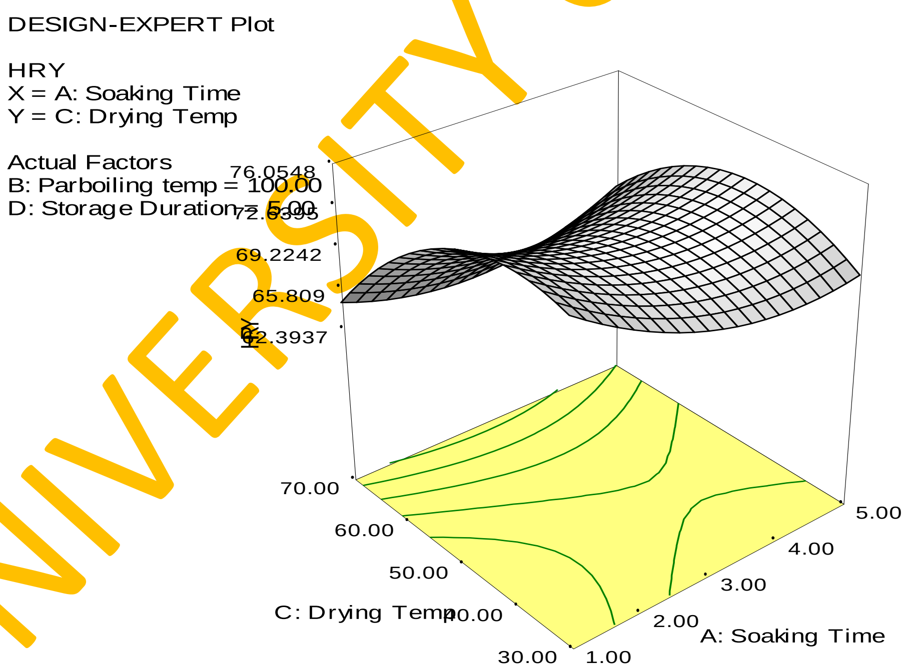

Fig.4.20: Effect of soaking time and drying temperature on HRY

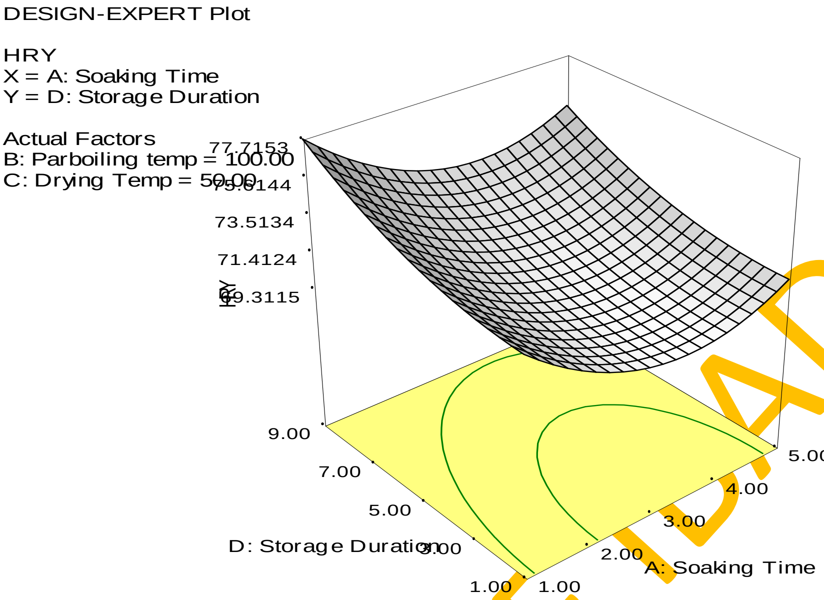

Fig.4.21: Effect of soaking time and storage duration on HRY

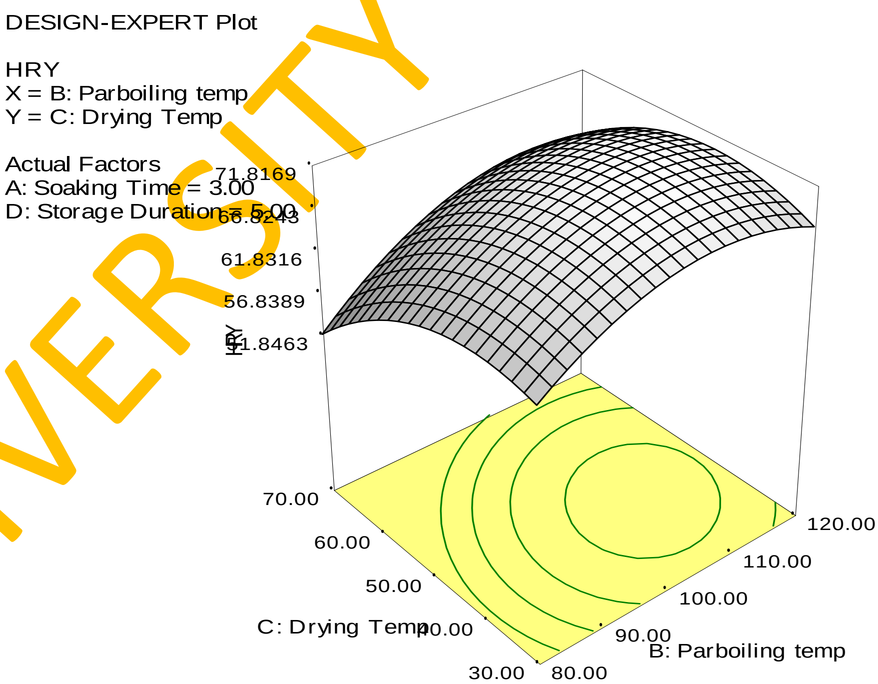

Fig.4.22: Effect of parboiling and drying temperature on HRY

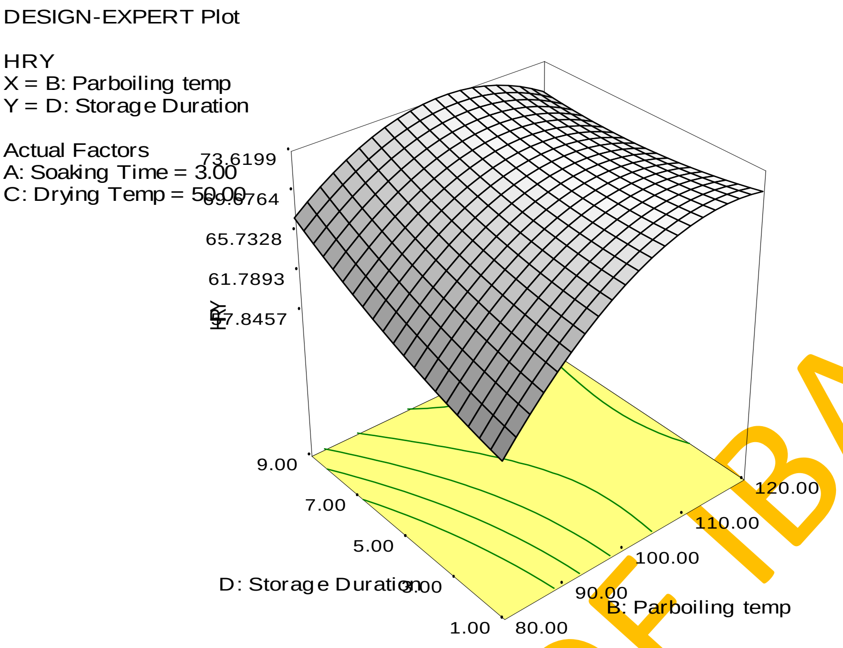

Fig.4.23: Effect of parboiling temperature and storage duration on HRY

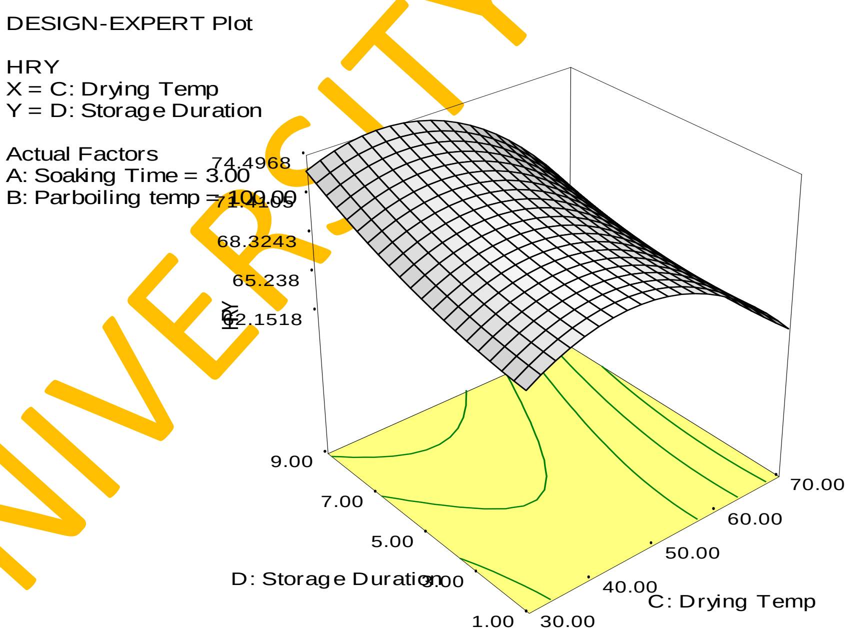

Fig. 4.24: Effect of drying temperature and storage duration on HR

4.1.4 Brokenness

Brokenness is another critical quality characteristic of milled rice. The degree of brokenness ranged from 0.81 to 83.08 %. The minimum value was obtained at 9 month of storage duration, 3 days soaking time, 120 ^{0}C parboiling temperature, and 30 ^{0}C drying temperature. The maximum value was at 1 (one) month storage duration, 1 day soaking time, 80 ^{0}C parboiling temperature, and 70 ^{0}C drying temperature. The results obtained for the brokenness was significant ($p < 0.05$) and the lack of fit test for the model was not significant. The non significant lack of fit test was favourable for the fitness of the model to define brokenness of *Ofada* rice as affected by processing conditions.

The overall mean value of the percentage brokenness was 27.90; the R^2 and adjusted R^2 were presented in Table 4.2. The standard deviation was14.13 and adequate precision of 7.257 measure the signal to noise ratio. The coefficient of R^2 recorded affirms the fitness of the model in the prediction of percentage brokenness of *Ofada* rice. The coefficient model that showed the effect of processing parameters on brokenness is presented (Table 4.3).

Broken grains can be classified into two, large and small broken or "brewers rice". Large broken are milled rice with length less than three quarters but more than one quarter of the average length of the whole kernel while small broken are milled rice with length less than one quarter of the average length of the whole kernel (Saleh and Meullenet, 2012). Response surface graphs showing the interactions of the effect of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temperature and drying temperature, parboiling and storage duration, drying temperature and storage duration of ricebrokenness were presented below (Figs. 4.25-4.30).

The effect of soaking and parboiling have shown that higher parboiling temperature and longer soaking time reduced the percentage of broken grains while reduction in parboiling temperature and decrease in soaking time increased broken grain (Fig.4.25). This report was also affirmed by the high coefficient of soaking time (S) and parboiling temperature (P) (Table 4.3). From the response surface graphs, it was also revealed that these processing operations were associated with percentage brokenness of *Ofada* either singularly or combinations. The relatively high percentage of broken fractions could be attributed to low moisture content (Gayin *et al*., 2009), also chalkiness indirectly contributes to rice breakage through easier cracking (Bhattacharya, 1980).

According to Marshall *et al*., (1993), parboiling of paddy at high temperature increases the degree of rice starch gelatinization. Well parboiled rice is harder and less subject to transverse breakage than raw rice. However, broken grain has found its utilisation in various recipes such as adjunct in wort/beer production and in other uses (Malomo *et al*., 2012). High drying temperature and relatively increase in soaking time also increased broken grains (Fig.4.26). However, Itoh and Kawamaura (1991) observed that as the degree of gelatinization increases from 2 to 60, the percentage of kernel breakage decreased from 7 to 1% in a linear manner. Broken Kernels reduce milling yield. Broken grains produced during milling are generally the result of immature, chalky, or fissured kernels all of which are weak and typically break during milling due to the substantial forces imparted to kernels in order to

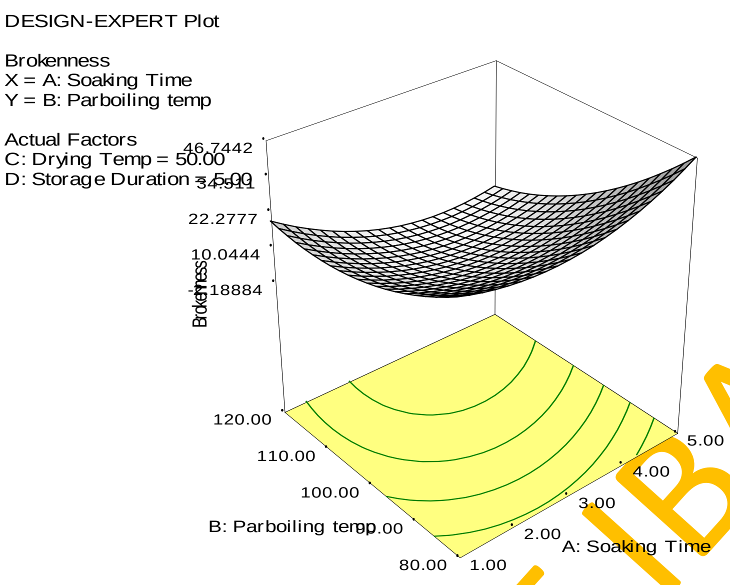

Fig.4.25: Effect of soaking time and parboiling temperature on brokenness

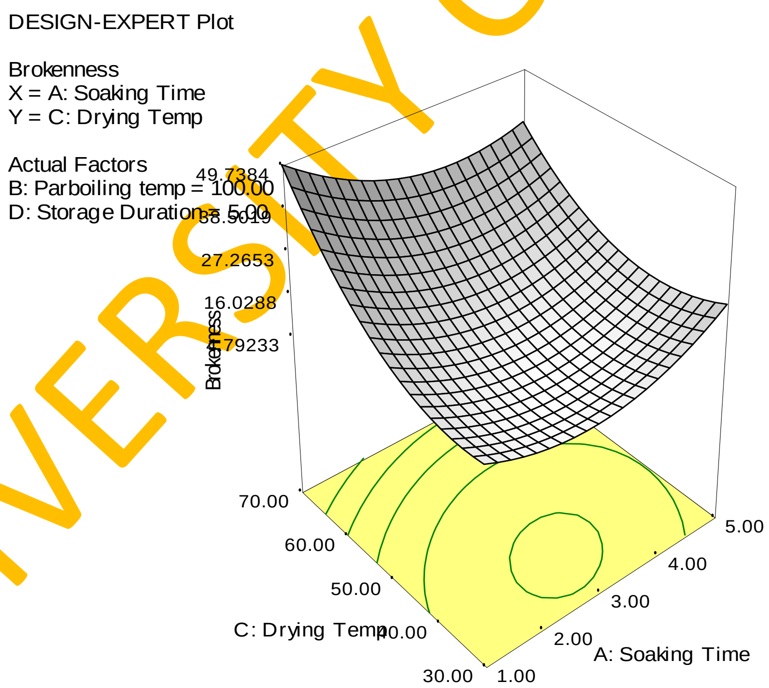

Fig. 4.26: Effect of soaking time and drying temperature on brokenness

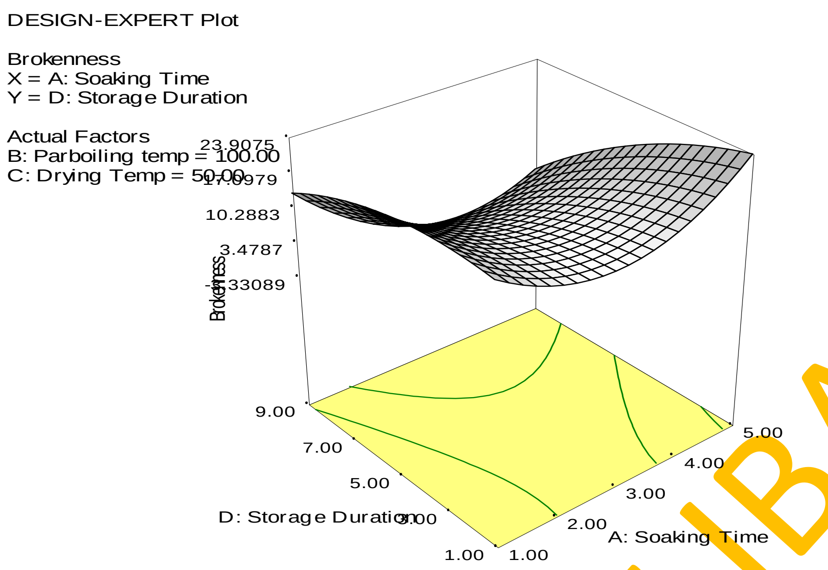

Fig.4.27: Effect of soaking time and storage duration on brokenness

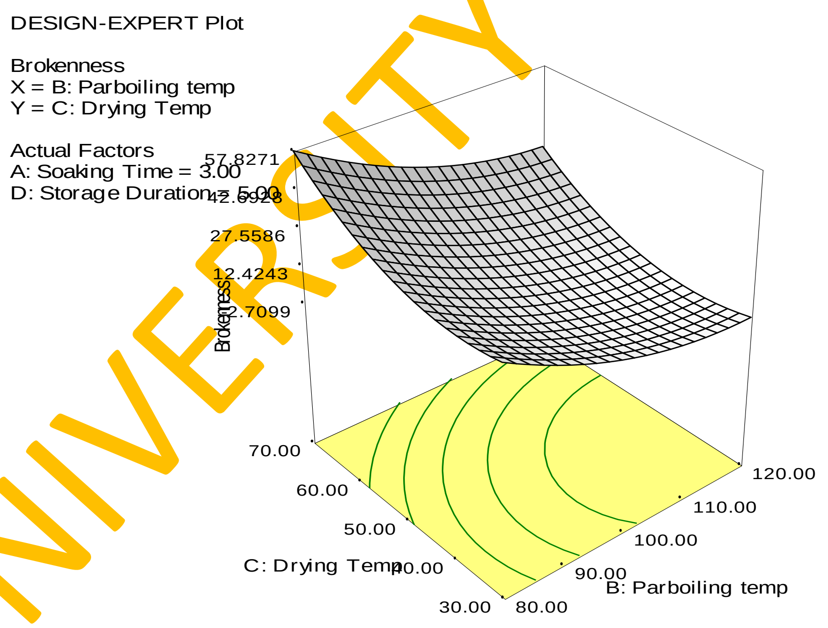

Fig.4.28: Effect of parboiling and drying temperature on brokenness

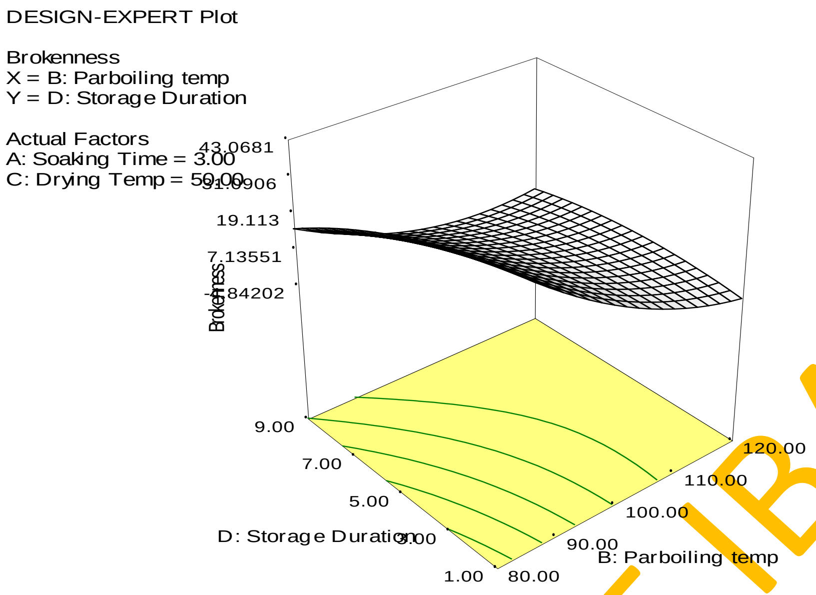

Fig.4.29: Effect of parboiling temperature and storage duration on brokenness

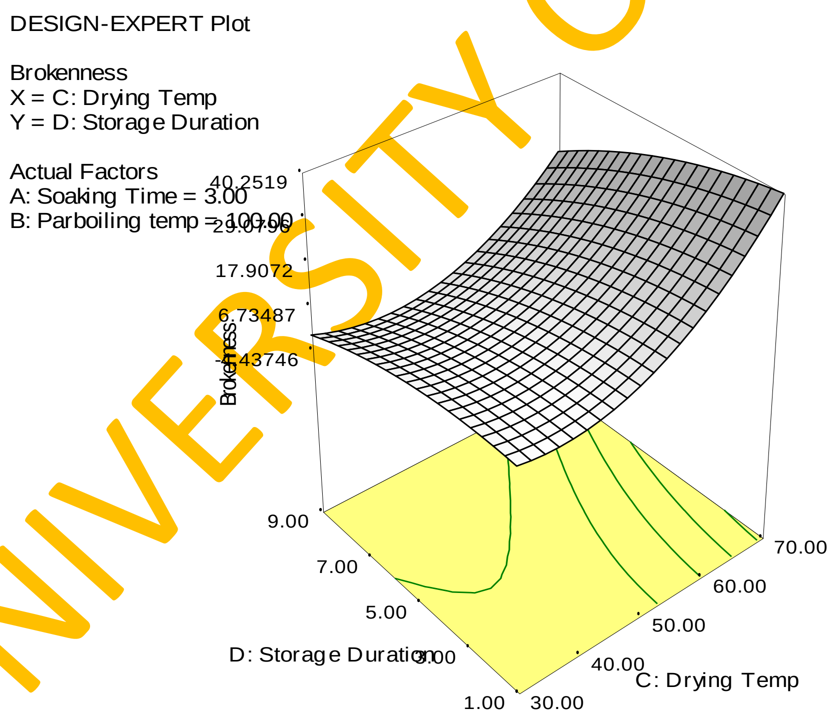

Fig.4.30: Effect of drying temperature and storage duration on brokenness

remove bran. Severe brokenness are only approximately 60 % of the value of head rice, HRY directly determines the economic value of rice (Siebenmorgen *et al.*, 2010).

The kernel of rice can become cracked in the field, during the dumping process, or during the milling process. Cracks are usually caused when moisture is migrating quickly within the kernel (chopping too fast, or moisture being added back to a dry kernel). Most broken rice is removed during the milling process to less than 40% in U.S in order to give the consumer high quality rice. Broken rice tends to get mushy during cooking and makes poor quality table rice.

4.1.5. Chalkiness

The degree of percentage chalkiness ranged from 0 to 49.64% and the mean percentage chalkiness was 12.34% (Table 4.1). There were significant differences ($p < 0.05$) in the results obtained for the percentage of chalkiness in relation to the processing conditions. The R^2, Adjusted R^2, predicted R^2 and adequate precision were presented (Table 4.2) while the standard deviation was 11.73. The coefficient of the model is presented in Table 4.3. The coefficient showed the impact of soaking and parboiling in the elimination of the chalkiness in rice kernel.The response surface graphs showing the effects of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temp and drying temp, parboiling and storage duration, drying temperature and storage duration on the percentage of chalkiness were presented below (Figs.4.31 – 4.36).

The deductions from the response surface plots revealed that reduction in soaking time, high parboiling temperature, low drying temperature and increased storage duration favoured low percentage of chalkiness (Figs.4.31–4.36). The rice varieties with minimum amount of chalkiness is considered as good quality grains in comparison with chalky ones which decreases the rice grain quality (Bhonsle and Sellappan, 2010). Chalkiness higher than 1 % is considered not acceptable in parboiled rice (Gayin *et al.*, 2009).

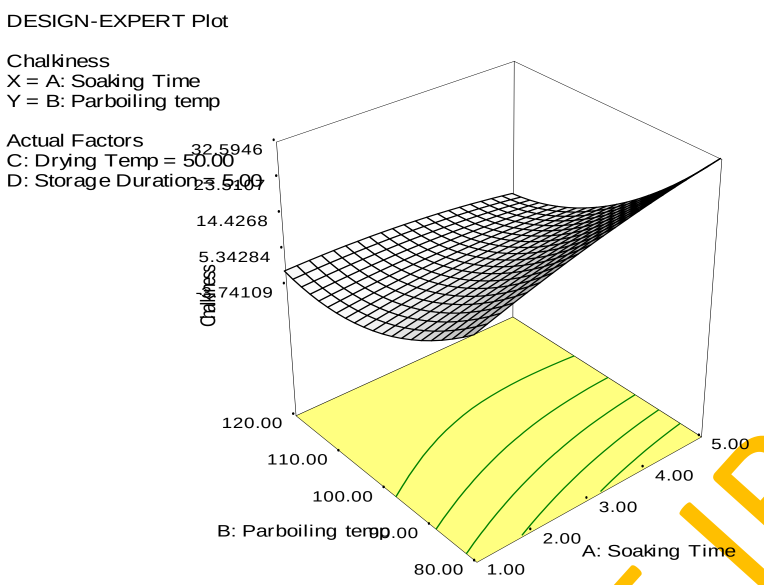

Fig.4.31: Effect of soaking time and parboiling temperature on chalkiness

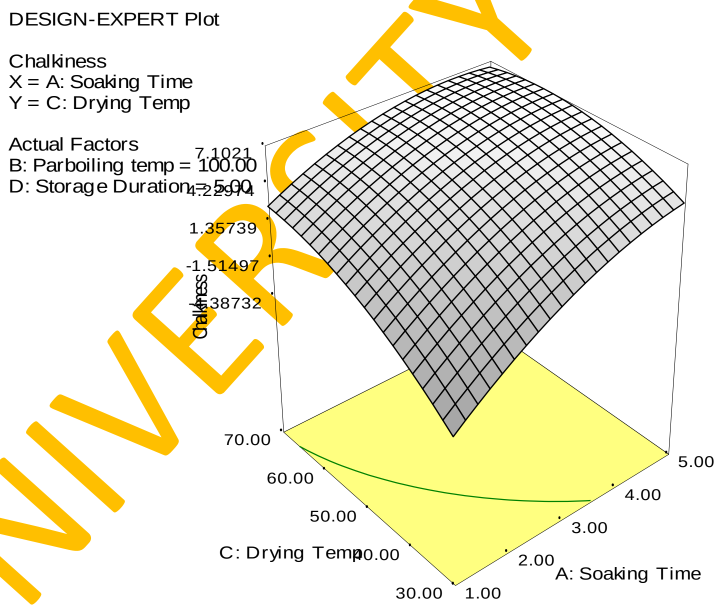

Fig.4.32: Effect of soaking time and drying temperature on chalkiness

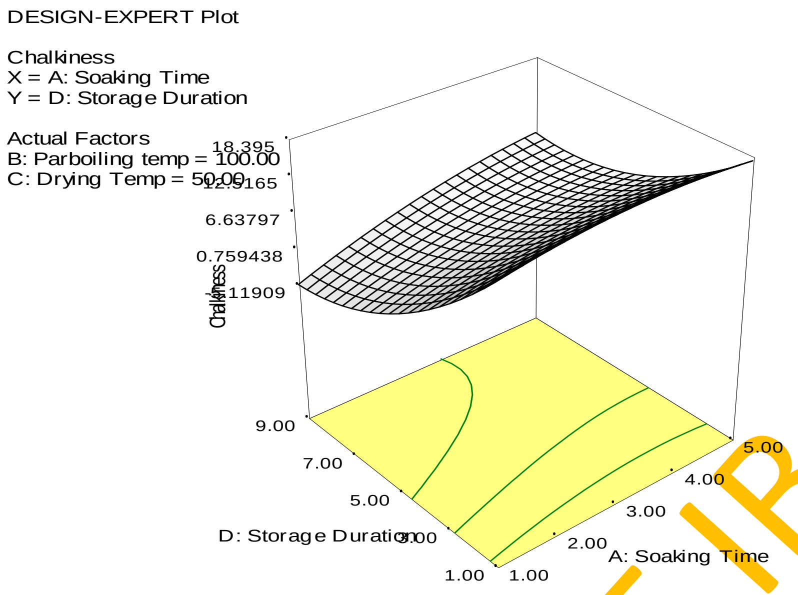

Fig.4.33: Effect of soaking time and storage duration on chalkiness

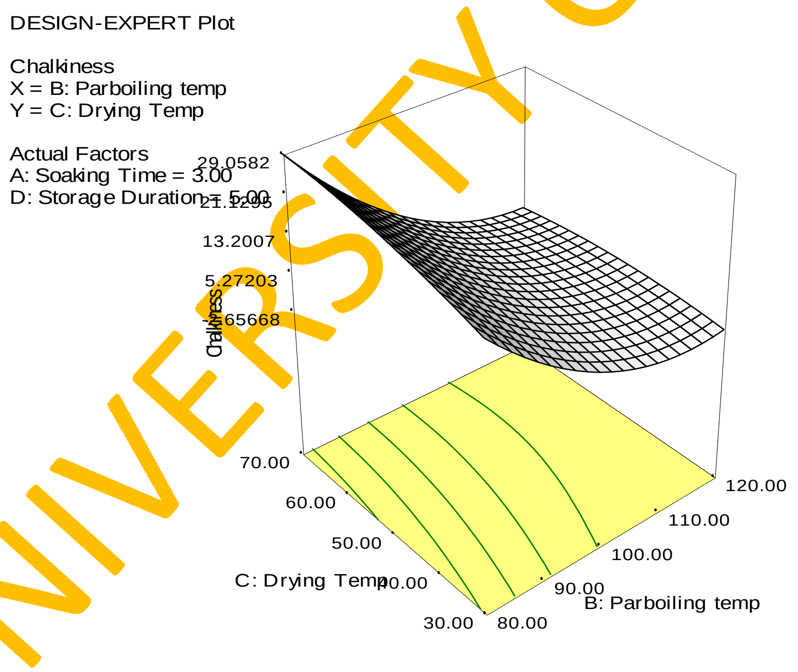

Fig.4.34: Effect of parboiling and drying temperature on chalkiness

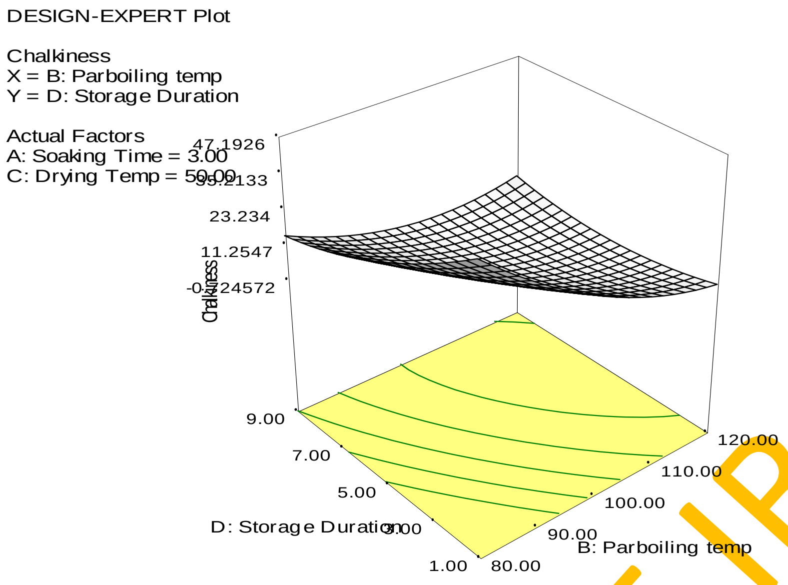

Fig.4.35: Effect of parboiling temperature and storage duration on chalkiness

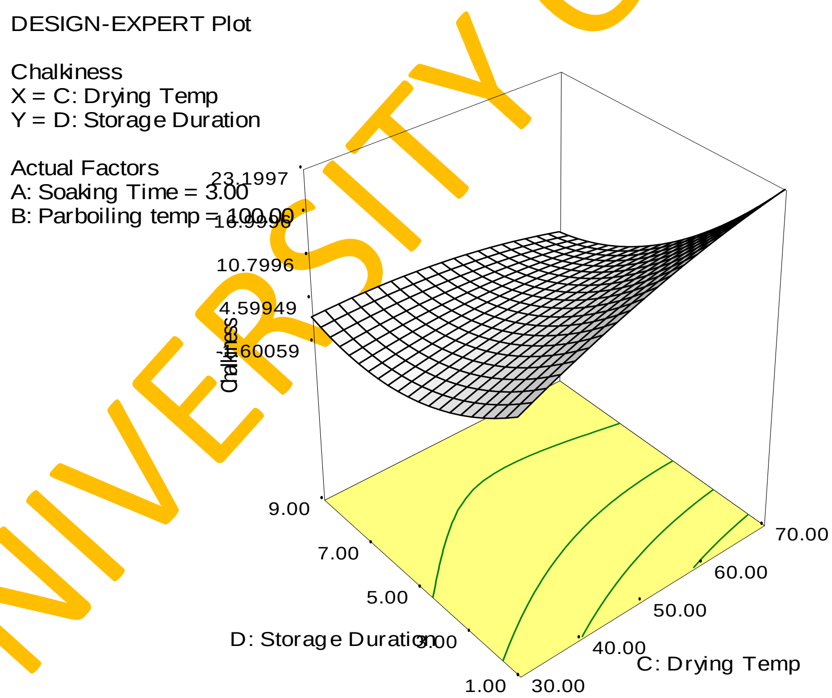

Fig.4.36: Effect of drying temperature and storage duration on chalkiness

Bhonsle and Sellappan (2010) reported 24.1-85% of chalkiness in some varieties of rice in India made up of white centre and white back based on the position and orientation of chalkiness. Chalkiness disappears upon cooking and has no effect on taste or aromahowever; it downgrades the grain quality and reduces milling recovery. The results obtained showed dependence of rice chalkiness which is mainly on parboiling temperature and partially on soaking time. The degree of gelatinization which results in the conversion of starch to gel depends on steaming temperature. Chalky rice occurs when part of the grain is whiter than the rest because this is where the starch has not developed properly and is a point of weakness.

Chalkiness and grain wholeness are the two characteristics that both domestic and international rice markets base their grading on. Two things known to cause chalkiness in the grains are the genetics of the rice variety and higher growing temperatures. Unfortunately, since farmers cannot manage their rice crops to reduce grain chalkiness nor can they do anything to change temperature; they must rely on growing varieties less susceptible to chalkiness. A lot of research is still on to find out why it has been so difficult to eliminate chalkiness from rice improvement programs (IRRI, 2007).The findings from this study have shown that appropriate processing technology could reduce chalkiness in rice grain.

4.1.6. Colour assessment of *Ofada* rice

Colour is an important attribute in acceptability of food products such as rice. The result of the colour lightness (L*) and colour values were presented (Table 4.1). The value of rice lightness ranged from 65.99 to 78.80. There exist significant differences at $p < 0.05$ on rice lightness obtained from the experiment. The closeness of the values of rice lightness to the standard (A4 paper of 91.83whiteness) was used to determine the percentage whiteness. The highest lightness was from *Ofada* rice stored for 5 months, soaked for 3 days, parboiled and dried at 120°C and 50°C respectively while lowest was from rice stored for 1 month, soaked for 5 days, parboiled and dried at 120°C and 70°C temperatures respectively.

The lack of fit test for the model is not significant with the F-value of 3.80. The coefficient of the mathematical quadratic model is presented (Table 4.3). High coefficients of drying (D) and storage (T) showed that the outcome of rice colour after processing is dependent on drying temperature and storage duration. The data in Table 4.3 revealed that increase in soaking time was favourable to the whiteness of *Ofada* rice while the effect of parboiling temperature was not prominent. The impact of low drying temperature is good for the processing of *Ofada* rice similar to the result of Adeyemi *et al.,* (1986) which recommended the drying of rice in shade under good aeration. High coefficient of drying (D) model also supported the impact of drying temperature on whiteness of milled rice (Table 4.3). The curve for the storage duration is concave downward with the mid experimental drying temperature most preferred to obtain light colour of rice which is more preferred in term of acceptability.

4.17. Effect of storage and processing conditions on colour value of *Ofada* rice

The results of colour value as calculated from a* and b* were presented (Table 4.1). There was no significant difference in the value obtained ($p > 0.05$). The highest colour value was obtained from paddy rice stored for 9 months and processed by soaking for 5 days, 80°C parboiling temperature and 30°C drying temperature while the minimum value was rough rice stored for only 1 month and treated by soaking for 5 days, parboiling at 120°C and drying at 70°C. The lack of fit test for the model was not significant with the F-value of 0.055 which was good for the fitness of the equation to describe the experiment. The R^2, adjusted R^2, predicted R^2, adequate precision were presented (Table 4.2). The quadratic coefficient of the model is presented (Table 4.3). The coefficient revealed that all the processing parameter contributed to the colour of *Ofada* rice.

As presented in the Table 4.1, colour value increased with increase in drying temperature, storage duration and soaking time while increase in parboiling temperature reduced colour value. This is similar to the investigation by Sareepuang *et al.*, (2008), that due to parboiling treatment, discolouration of grain occurs which decreases the lightness value. The negative effect of parboiling is as a result of discoloration of rice mainly caused by Maillard type non enzymatic browning and the processing conditions determine the intensity of colour during parboiling.

4.1.8. Optimisation of physical characteristics of *Ofada* rice

The physical qualities selected for optimisation of *Ofada* rice include maximum length, maximum width, minimum brokenness, maximum head rice yield, minimum chalkiness, and maximum colour lightness. The best optimum storage and processing conditions obtained revealed storage of paddy for 1 month, soaking in water for 1 day, parboiling at 119.92°C and drying at 30.32°C. Other solutions and their yields were presented (Table 4.4). The prediction would be useful for upgrading the present quality of*Ofada* rice and sustenance of its physical quality. Hence, this would also allow healthy competition of indigenous rice with imported rice.

Table 4.4: Predicted solutions for optimisation of physical qualities of Ofada rice

No	Soaking time,days	Parboiling temp. °C	Drying temp.° C	Storage , month	Length mm	Width mm	Breadth mm	HRY %	Brokenness %	Chalkiness %	Lightness	Desirability
1	1.00	119.92	30.32	1.00	6.005	3.016	2.349	73.22	3.606	0.005	77.612	0.88
2	1.00	119.96	31.76	1.31	6.008	2.998	2.31	73.532	4.495	0.001	78.043	0.872
3	1.62	120.00	30.00	1.00	6.003	3.009	2.364	70.865	-1.339	-0.18	76.72	0.8723
4	1.18	120.00	37.94	1.00	6.061	2.999	2.266	74.313	2.463	2.942	77.238	0.872
5	1.00	117.27	30.80	1.00	5.947	3.029	2.36	73.894	3.535	0.247	76.643	0.872
6	1.00	116.84	30.00	1.19	5.924	3.027	2.36	73.674	4.228	-0.479	76.746	0.872
7	1.00	116.07	32.27	1.00	5.933	3.03	2.349	74.477	3.56	0.974	76.238	0.872
8	1.28	120.00	36.72	2.40	6.011	2.944	2.198	73.267	4.975	-6.276	78.65	0.872
9	4.51	120.00	33.17	1.00	6.114	2.781	2.254	68.846	-2.537	-6.276	73.974	0.872

4.2. Chemical quality of *Ofada* rice

The results of the effect of processing conditions and storage on the chemical qualities of *Ofada* rice (OS-6) were presented (Table 4.5).

4.2.1. Moisture content of *Ofada*rice

The result of percentage moisture content ranged from 4.35 to 10.30 % with 7.64 % as the mean value. It was shown that quadratic model best fit the experiment while there existed significant differences ($p<0.05$) in moisture contents of*Ofada* as influenced by the processing conditions. The R^2, adjusted R^2, predicted R^2, adequate precision were presented (Table 4.6). A very low value of standard deviation (0.56) confirmed the fitness of the model andcoefficient of the model in term of actual factor is presented (Table 4.7). The response surface graphs on the effects of interactions of two variables (soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temperature and drying temperature, parboiling and storage duration, drying temperature and storage duration) were presented (Figs.4.55-4.60).

The highest amount of moisture (10.30 %) was recorded at 1 month of paddy storage, 5 days of soaking, 80^{0}C parboiling temperature, and 30^{0}C drying temperature while the lowest (4.35%) was at the storage duration of 9 months, 1 day soaking, 120^{0}C parboiling and 50 ^{0}C drying temperature. Adeyemi *et al.*, (1985) on the study of rice processing options for Nigerian rice industry recorded a moisture range between 10.12 to 13.88%; Ebuchi and Oyewale (2007) between 7.5-11.2%. The variation may majorly be influenced by the variety and the prevailing condition of treatment, processing and environmental factors (Ebuchi and Oyewole, 2007).

The low amount of moisture recorded may be due presence of wax content in brown rice seed coat and on the pericarp which reduces water absorption (Roy *et al.*, 2011). The post harvest stability of the grains depend on their moisture contents at harvest, conditions prevailing in their immediate environment during transportation, pre-processing and storage; and also on their moisture sorption behaviours (Ajisegiri *et* *al*., 2007). Water as the most important storage factor plays a significant role in storage stability of agricultural produce depending on the chemical composition and physical structure of the produce and on the form in which it exist in the produce (Ajisegiri and Chukwu, 2004). High coefficient value of soaking revealed its effect on moisture content of rice.

Table 4.5: Chemical composition of *Ofada* rice

Run	Soaking day	Parboiling °C	Drying °C	Storage Month	Moisture %	Protein %	Ether extract %	Ash %	Carbohydrate %	Crude fibre %	Fatty acid %	Metabolizable Energy kcal/100g	Amylose %
1	1	120	70	1	8.95	9.52	1.93	0.58	78.65	0.37	1.56	379.7	21.34
2	1	80	70	1	7.45	8.67	1.66	0.57	81.31	0.34	2.9	385.26	23.67
3	5	80	30	5	7.8	10.00	1.64	1.02	80.03	0.28	3.06	381.92	20.93
4	5	80	30	1	10.3	8.71	1.61	0.46	78.63	0.29	4.78	373.85	25.29
5	3	80	30	9	5.48	10.44	1.81	0.77	81.36	0.14	3.22	393.79	19.71
6	5	80	50	5	8.35	9.05	1.36	0.53	80.54	0.17	2.95	381	21.76
7	1	120	30	5	7.8	9.74	1.72	1.01	79.51	0.22	1.37	382.37	20.93
8	5	80	70	1	8.01	8.68	1.62	0.57	80.78	0.34	2.09	382.77	23.05
9	3	120	70	9	4.72	9.21	1.04	0.54	84.35	0.14	2.84	384.79	23.55
10	3	120	50	5	8.75	9.43	1.69	0.53	79.41	0.19	1.86	380.52	18.47
11	5	120	30	9	5.25	9.96	0.7	0.65	83.29	0.15	1.42	390.4	25.58
12	1	100	50	5	8.65	9.31	1.8	0.93	79.13	0.18	1.51	374.62	19.09
13	3	120	70	5	8	9.19	1.91	0.63	81.04	0.23	1.49	388.23	20.5
14	1	100	50	9	6.93	8.86	1.18	0.78	82.06	0.19	1.78	385.1	25.51
15	5	120	50	9	4.35	9.31	1.98	0.78	83.4	0.18	1.79	399.07	20.38
16	1	120	70	1	9.1	8.42	1.24	0.58	80.29	0.37	1.23	376.55	20.98
17	3	100	50	5	6.65	9.83	1.42	0.74	81.13	0.23	3.04	386.94	18.12
18	5	100	50	5	9.86	8.92	1.68	0.54	78.66	0.34	1.82	375.46	24.86
19	1	80	30	1	9.7	8.78	1.71	0.47	79.05	0.29	3.2	376.7	26.54
20	1	120	30	1	9.3	10.14	1.27	0.47	78.58	0.24	1.43	376.26	22.39
21	5	100	30	9	4.83	9.31	2	0.52	83.18	0.16	2.66	398.33	19.95
22	1	80	70	5	8.95	9.07	0.98	0.7	80.11	0.19	1.64	367.18	24.44
23	5	80	70	9	5.95	9.48	3.76	0.71	79.98	0.12	3.66	400.4	20.5
24	1	80	30	9	6.57	10.35	2.25	0.11	81.7	0.13	2.41	393.23	22.28
25	1	120	30	1	9.2	9.87	1.36	0.47	78.86	0.24	1.59	377.14	21.46

Table 4.6: ANOVA of regression of chemical properties as a function of storage and processing conditions

Parameters	p-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Moisture,%	<0.0001	0.9573	0.8976	0.4633	13.954
Protein content, %	0.0297	0.8253	0.5806	-1.0142	5.917
Ether extract,%	0.0246	0.8332	0.5998	-0.6776	10.048
Ash content,%	0.6911	0.5149	-0.1643	-7.3242	3.201
Crude fibre, %	0.0082	0.8717	0.692	-1.4198	7.063
Carbohydrate,%	0.0012	0.917	0.8009	0.0038	9.357
Fatty acid,%	0.0644	0.7867	0.4881	-2.2444	5.182
Metabolizable energy,kcal/100g	<0.0001	0.9681	0.9234	0.2367	17.553
Amylose, %	0.038	0.814	0.5535	-2.2422	6.241

Table 4.7: Coefficient of model on effect of storage and processing parameters on chemical quality of *Ofada* rice

	Moisture %	Protein %	Fat %	Ash %	CHO %	Crude fibre %	fatty acids %	ME kcal/kg	Amylose %
Intercept	-3.02	19.94	1.32	1.03	93.27	-0.1	16.71	448.37	3.16
S	3.43	-12.8	-0.47	-0.53	-1.44	$-4.96x10^{-4}$	-0.63	-7.81	7.6
P	0.34	-0.17	-0.05	-0.02	-0.18	0.01	-0.16	-1.72	0.76
D	-0.19	0.02	0.06	0.04	-0.05	$-7.48x10^{-3}$	-0.11	0.68	-0.83
T	0.43	0.5	0.5	0.11	-1.23	-0.02	-0.58	2.17	-3.24
S^2	-6.37	0.09	0.1	0.05	0.12	$-5.58x10^{-3}$	0.02	1.13	-0.99
P^2	$-1.53x10^{-3}$	$9.41x10^{-4}$	$2.8x10^{4}$	$7.05x10^{-5}$	$4.87x10^{-4}$	$-8.45x10^{-5}$	$2.63x10^{-4}$	$7.93x10^{-3}$	$-4.01x10^{4}$
D2	$1.66x10^{-3}$	$-2.89x10^{-4}$	$-4.33x10^{-4}$	$-2.49x10^{-4}$	$5.31x10^{-5}$	$3.98x10^{-5}$	$-1.09x10^{-4}$	$-6.31x10^{-3}$	$8.42x10^{-3}$
T2	-0.05	-0.01	$5.97x10^{-3}$	-0.01	0.05	$4.82x10^{-4}$	0.02	0.31	0.09
SP	$-0.08x10^{-3}$	$8.69x10^{-4}$	$4.23x10^{-3}$	$2.49x10^{-3}$	$-1.58x10^{-3}$	$3.70x10^{-4}$	$6.08x10^{-3}$	0.04	-0.02
SD	$-2.43x10^{-3}$	$3.99x10^{-4}$	$-9.31x10^{-3}$	$6.57x10^{-5}$	$9.41x10^{-3}$	$-5.34x10^{-5}$	$2.85x10^{-3}$	-0.09	0.01
ST	-0.02	0.03	-0.04	$5.65x10^{-3}$	0.05	$-1.04x1010^{-3}$	-0.01	-0.19	0.01
PD	$-8.31x10^{-5}$	$-4.13x10^{-5}$	$4.26x10^{-6}$	$-1.33x10^{-4}$	$6.28x10^{-4}$	$5.27x10^{-5}$	$9.10x10^{-4}$	$2.89x10^{-3}$	$5.52x10^{-4}$
PT	$-5.56x10^{-3}$	$-3.5x10^{-3}$	$-4.96x10^{-3}$	$3.26x10^{-4}$	0.01	$1.01x10^{-4}$	$1.66x10^{-3}$	-0.02	0.02
DT	$5.56x10^{-3}$	$-7.44x10^{-4}$	$1.87x10^{-3}$	$-1.12x10^{-5}$	$-6.91x10^{-3}$	$-2.53x10^{-4}$	$5.51x10^{-3}$	-0.03	$9.49x10^{-3}$

According to Roy *et al.*, (2000), it is believed that milled and brown rice exhibit different rates of moisture absorption with milled rice initially absorbing water at a faster rate than brown rice because the milling treatment removes the outer protective layers of rice caryopsis, the endosperms of milled rice becomes relatively prone to water absorption (Siebenmorgan and Meullenet, 2004). However, it could be observed that the presence of some bran layer that is usually remained on *Ofada* rice seed coat and on the pericarp could be responsible for the reduction of water absorption, hence the low moisture content.

4.2.2 Protein content of *Ofada* rice

The result of the percentage protein contents ranged from 8.42 to 10.44% with the average mean of 9.37 % (Table 4.5).There were significant differences ($p < 0.05$) in protein contents of the milled *Ofada* rice as affected by storage duration and processing condition. The R^2, adjusted R^2, predicted R^2 and adequate precision were presented in Table 4.6. The non significance lack of fit test shown by ANOVA was good for the model. The coefficient of the model is presented (Table 4.7).Drying temperature (D) and storage duration (T) as processing parameters have positive influence on protein content of rice. The response surface plots for the effect of interaction between two variables of the processing conditions were given (Figs. 4.37 – 4.42).

The highest amount of protein (10.49 %) was recorded in *Ofada* rice paddy stored for 9 months, soaked for of 5 days, parboiled at 80°C, and dried at 30°C while the lowest (8.92 %) was at 1(one) month of paddy storage, 5 days of soaking, 120°C parboiling temperature, and 70°C drying temperature. The result of some protein contents were higher than protein contents reported by some authors. Megat- Rusydi *et al.*, (2011) reported a range of 4.78 - 6.45 %; Ebuechi and Oyewole (2007) 6.95 - 7.30 %; Oko and Ugwu (2011), 1.53 %. This investigation had showed the significance of *Ofada* rice in human nutrition compared to other varieties of rice. However, the result of the protein content was related to the range obtained by Otegbayo *et al.*, (2001) on two local rice varieties from Ekiti, Nigeria (6.85-8.75 %). The variation may be as a result of processing conditions, types of soil where the rice is cultivated, the varietal differences, harvesting and handling (Abbas *et al.*, 2011). This study revealed the effectiveness of processing operations in improving the nutritional quality of rice.

The response surface plots shown that soaking time produced an upward curve with extremes (1 and 5 days) favouring increase in protein (Figs. 4.37, 4.38, and 4.39). The effect of parboiling temperatures and drying were opposite. Parboiling temperature brought about a relative improvement in protein contents (Figs. 4.38, 4.40 and 4.41), drying showed opposite effects (Figs.4.38, 4.40 and 4.42).

Rice polishing operation may lead to loss of 29 % of the protein (Abba *et al.*, 2011). It was also recorded that the differences in protein contents between two varieties of rice of about 2 g per 100 g may not at first right appear to be large, but on accumulation the changes may be very important. The significance of the protein contents can be attributed to the effect of parboiling temperature. High heat treatment such as high parboiling temperature can reduce protein during processing while mild temperature treatment could assist in retaining protein in food under processing although this could be dependent on parboiling time. Patindol *et al.*, (2008) in the experiment on effect of parboiling on rough rice using mild and severe parboiling temperature, the result showed that parboiling at severe temperature reduced protein content of rice compared with the control and this also varied with evaluated cultivars.

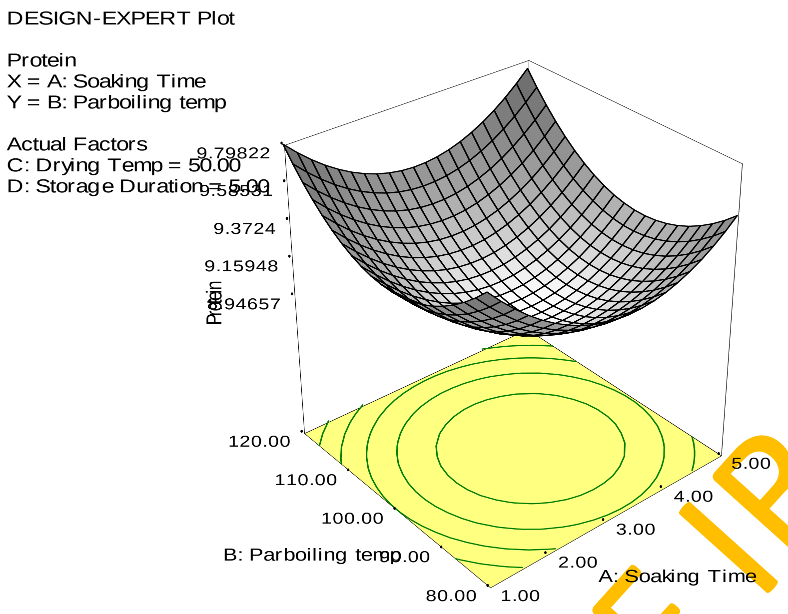

Fig.4.37: Effect of soaking time and parboiling temperature on protein

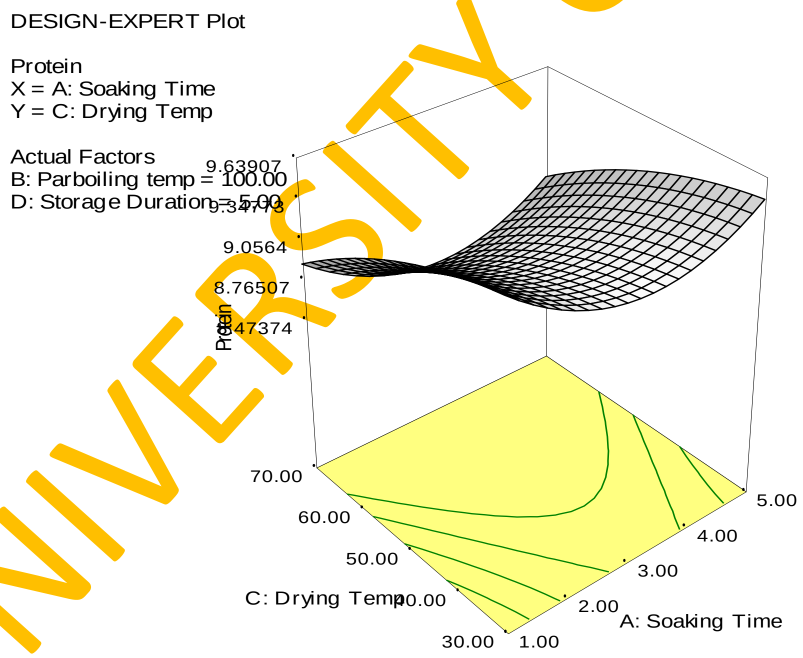

Fig. 4.38: Effect of soaking time and drying temperature on protein

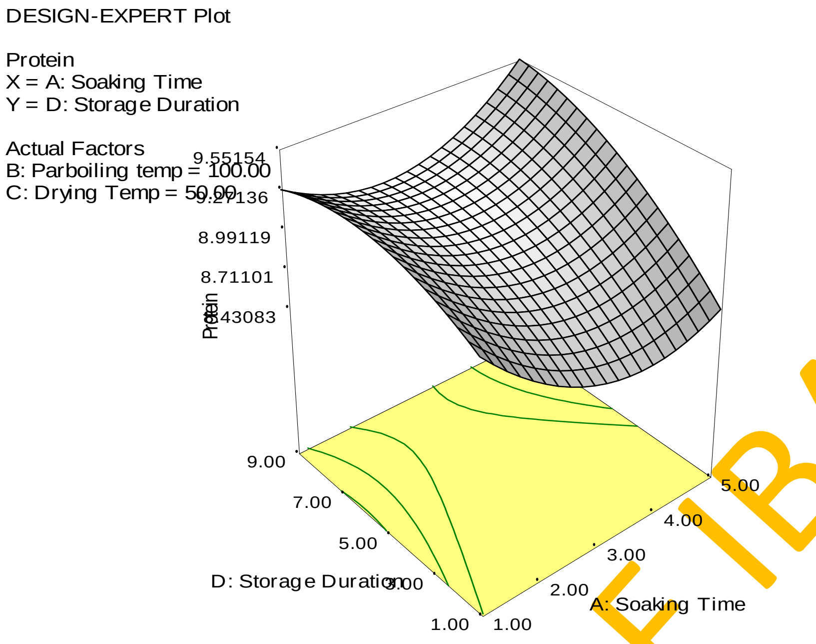

Fig.4.39: Effect of soaking time and storage duration on protein

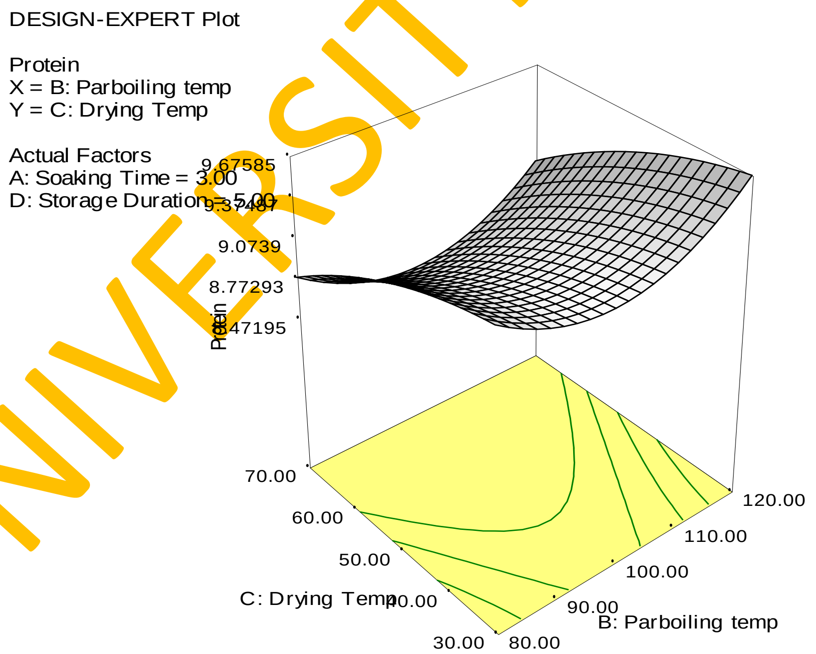

Fig. 4.40: Effect of parboiling and drying temperature on protein

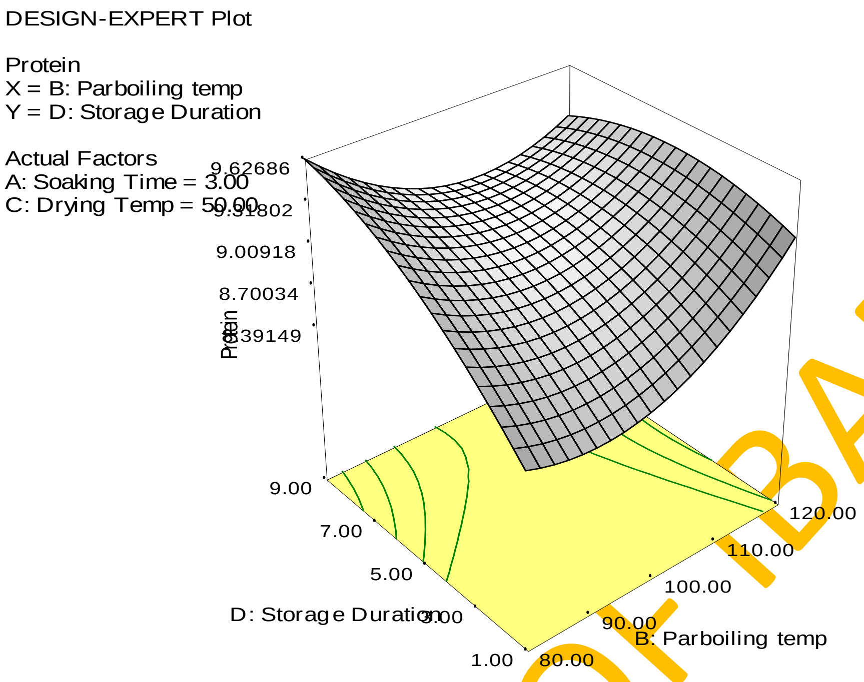

Fig.4.41: Effect of parboiling temperature and storage duration on protein

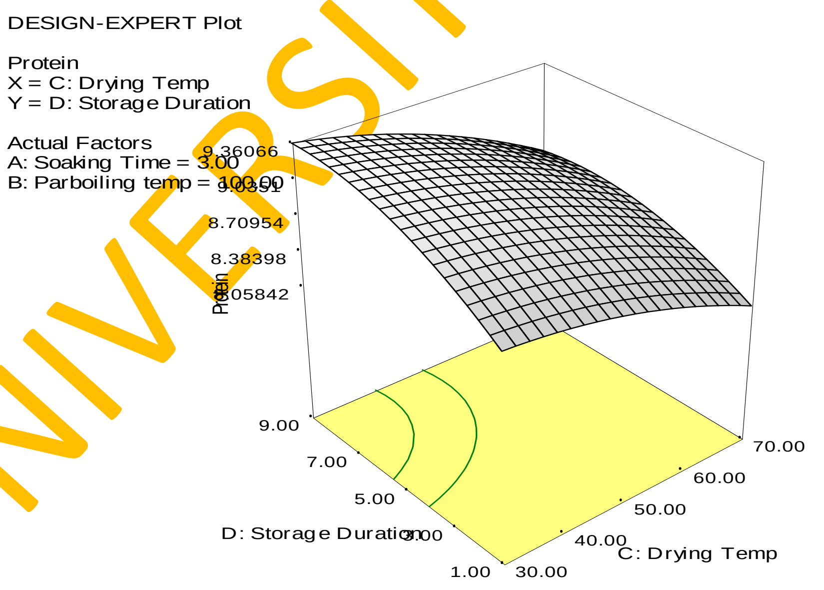

Fig. 4.42: Effect of drying temperature and storage duration on protein

Solubility of protein during soaking can also contribute to the variation of protein contents in *Ofada* rice by the process of leaching into the water during soaking which may also be relative to the soaking time.According to Zhou*et al.,* (2001), ageing of rice do not give any significant change in protein during storage, although its general solubility may be reduced. The effect of soaking on chemical composition of processed rice has also been established by Sareepuang*et al*., (2008). The study concluded that soaking of rice in 50^0C water produced the highest amount of protein. Rice proteins are valuable because they are colourless and having a bland taste. Rice proteins are non allergic and possessing cholesterol reducing properties (Chrastil, 1992). The milled rice protein has less protein while brown rice shows maximum retention of protein (Ellis *et al*., 1985).

4.2.3. Fat content of *Ofada*rice

The result of the effect of processing condition and storage duration on fat ranged from 0.70 to 3.76 % with mean value at 1.65 % (Table 4.5). There were significant differences at $p < 0.05$ in the result obtained due to the varied levels of processing conditions and storage duration. One day of soaking, 80^0C of parboiling, 70^0C drying temperature and 9 months storage produced the highest value of fats (3.76 %) while the lowest (0.70 %) was also recorded at the same storage duration but the treatment involved 3 days of soaking, 120^0C parboiling temperature, and 30^0C drying temperature.

The lack of fit was not significant which was good for the model prediction. The R^2, Adjusted R^2, predicted R^2, and adequate precision were presented (Table 4.6). Low values of standard deviation and PRESS values were 0.36 and 12.97 respectively which favoured the reliability of prediction. Adequate precision of 10.048which is greater than 4 gave an indication that this model can be used to navigate the design. The coefficient of the model showing the effect of processing units and their interactions is presented (Table 4.7).

The response surface graphs showing the effects of interactions of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling and drying temperature, parboiling and storage duration, drying temperature and storage duration on fat composition of *Ofada* were presented (Figs.4.43- 4.44).

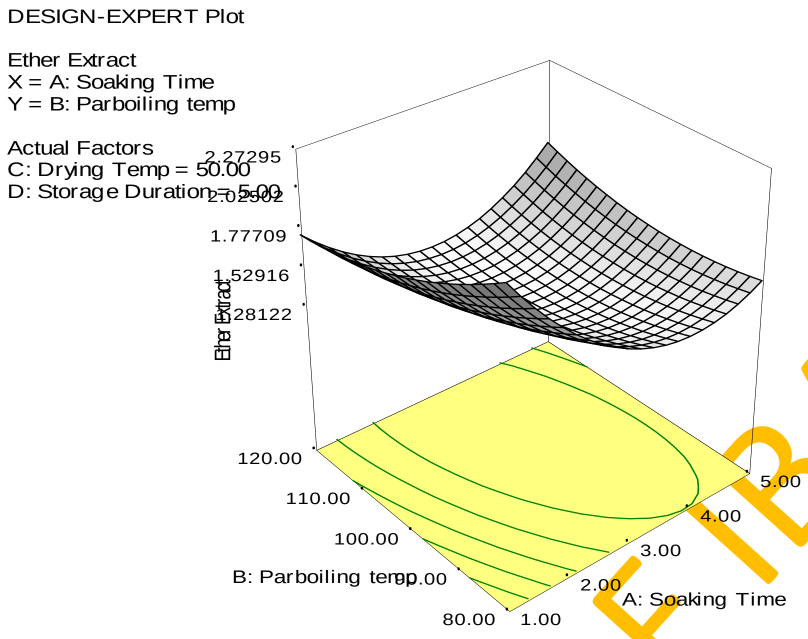

Fig.4.43: Effect of soaking time and parboiling temperature on fat

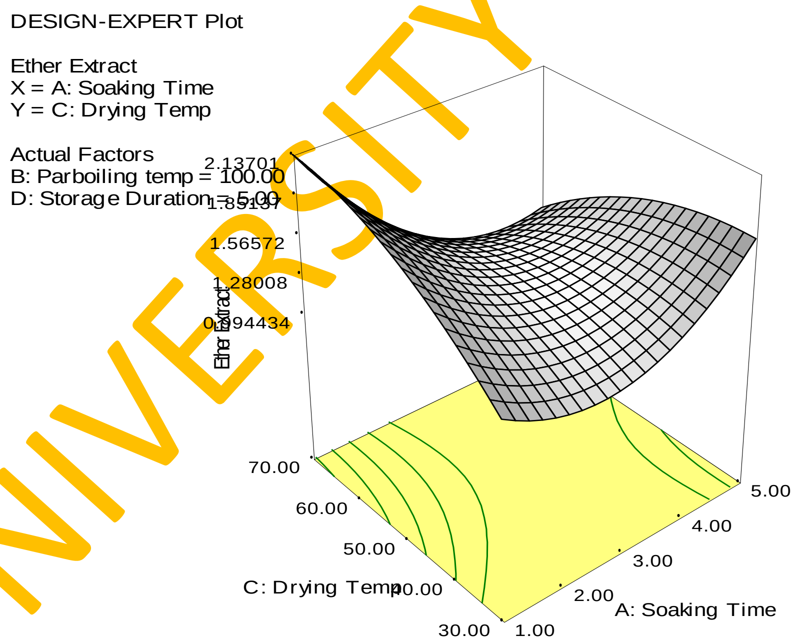

Fig. 4.44: Effect of soaking time and drying temperatureon fat

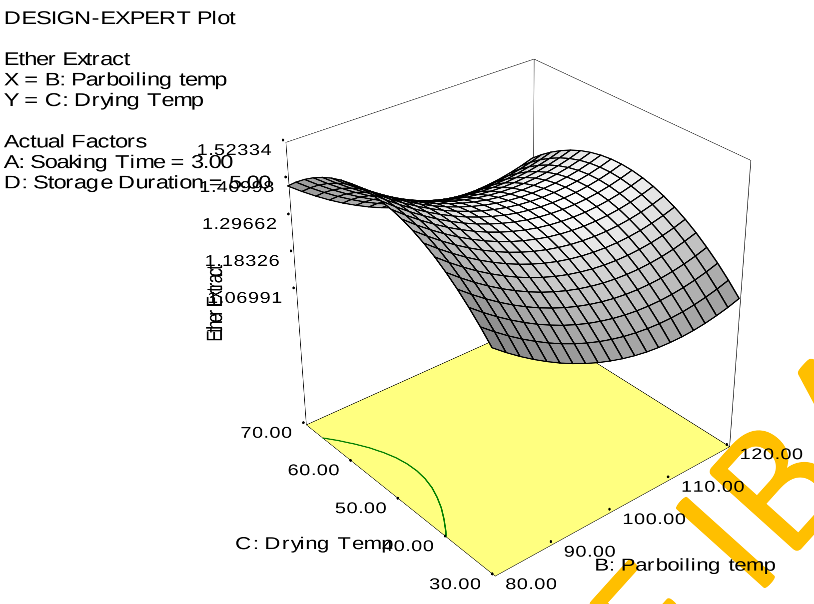

Fig.4.45: Effect of parboiling and drying temperature on fat

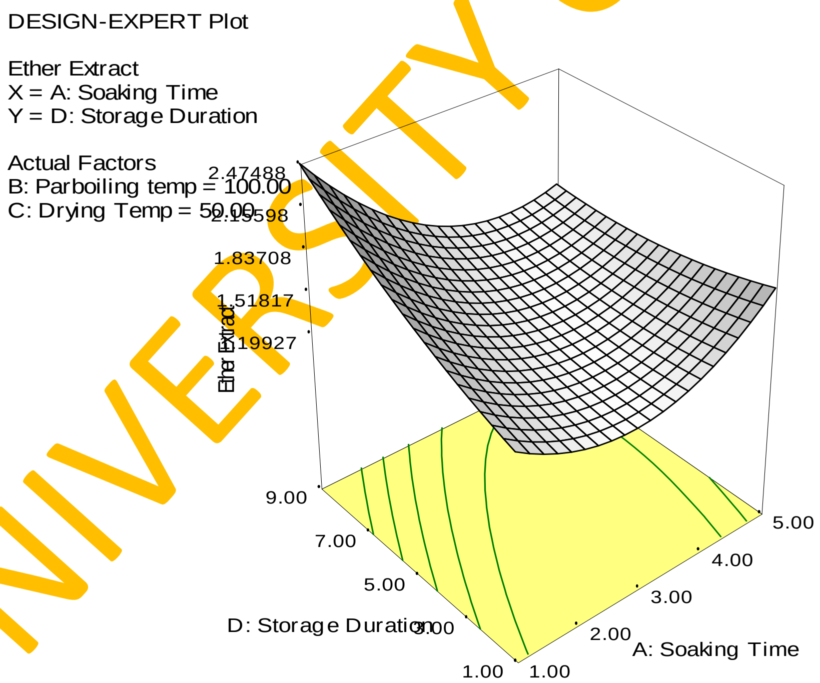

Fig. 4.46: Effect of soaking time and storage duration on fat

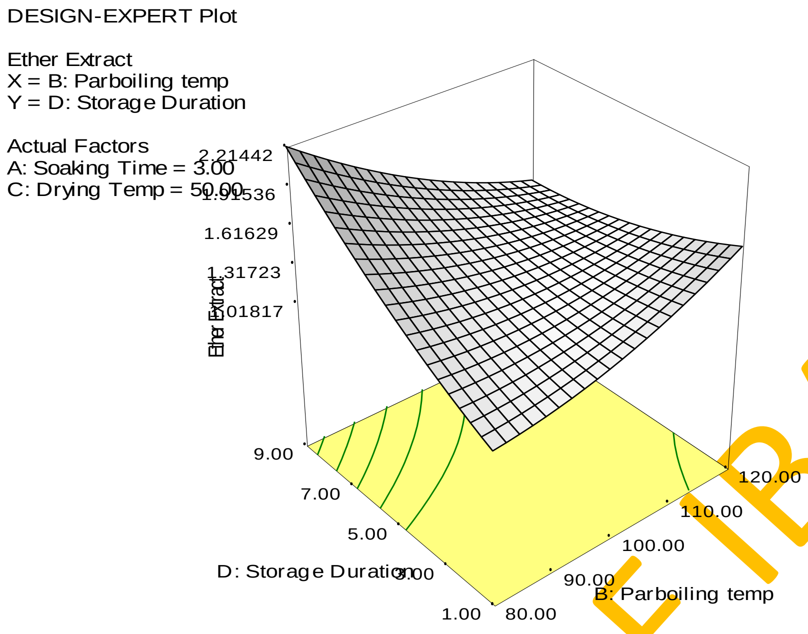

Fig.4.47: Effect of parboiling temperature and storage duration on fat

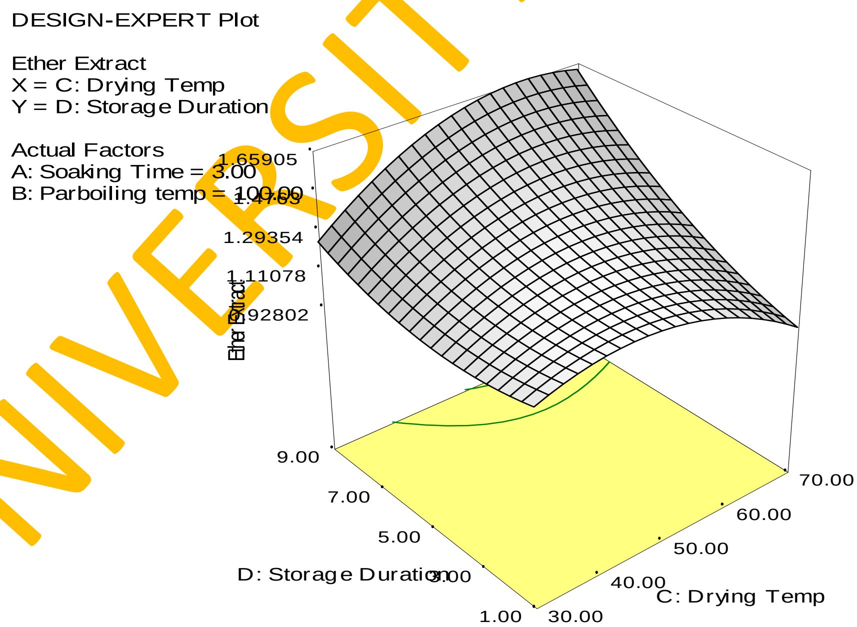

Fig. 4.48: Effect of drying temperature and storage duration on fat

Soaking period of between 3 – 4 days produced the lowest amount of fat as shown by the graphs while 1 and 5 days soaking were responsible for the high fat contents recorded (Figs.4.43,4.44, and 4.45). It was discovered from the graphs that the fat concentrations relatively reduced with increase in parboiling temperature which showed that 80°C parboiling temperature accorded the highest lipid content (Figs.4.43, 4.46 and 4.47). High temperature increases extraction of fat (Fennema, 1996).The drying temperature of 30°C produced lowest amount of fat and the lipid content increased with elongation of storage (Figs. 4.44, 4.47and 4.48).

Zhou *et al.*, (2001), recorded lipid content of 1.65 – 1.75 % for rice stored for 12 months with lipid content decreasing with period of storage. However, this was not in line with the result obtained from this study as the highest percentage of 3.76 was recorded at 9 months of storage. According to Akinoso and Adeyanju (2010), oil recovery and yield is dependent on solvent and the method of extraction. Large deposit of oil was found in *Ofada* rice bran in the experiment conducted by Akinoso and Adeyanju, (2010), which ranged between 11.3 – 14.50 % as affected by the treatment condition(roasting temperature and roasting duration). This has shown that large deposit of oil in *Ofada* rice is found in the bran which invariably might have been removed during polishing and processing.

Storage duration has effect on the fat compared to the processing conditions as shown by the high coefficient of storage (T) (Table 4.7). Similar work by Patindol *et al.*, (2008), where rough rice were subjected to parboiling at temperature of 100^0C and 120^0C recorded, percentage lipid ranged from 0.30 to 0.84 which cut across the various four cultivars investigated. The low fat content has revealed that rice may not be quickly prone to auto-oxidation and rancidity. Rice lipids are usually stable in the intact spherosomes in the cell. However, when the lipids membrane is destroyed by phospholipase as a result of physical injury or high temperature, lipid hydrolysis is initiated by the action of lipases (Zhou*et al.*, 2001).

4.2.4. Ash content of *Ofada* rice

Ash content is the approximation of mineral composition of a food sample. The result of ash contents ranged from 0.11 to 1.02 % with the mean value at 0.63. The highest amount of ash (1.02 %) was obtained at processing condition; 5 months of storage duration, 1 day soaking, 80^{0}C parboiling temperature, and 30^{0}C drying temperature while the minimum level of ash was obtained at 5 months storage duration, 5 days of soaking, 80^{0}C parboiling

temperature, and 30 ^{0}C drying temperature. The values for R^2, adjusted R^2, predicted R^2 and adequate precision were presented (Table 4.6) and the coefficient of model depicting effect of processing parameters and storage on ash is shown (Table 4.7).

Negative predicted R^2 showed that mean was the best predictor of the effect of processing parameters on ash content of *Ofada* rice. The extremes soaking time (1 and 5 days) showed maximum increase of ash while the variation in parboiling temperature did not depict notable changes in the ash content (Table 4.7). The result obtained in this experiment was low compared to the ash content obtained by Chukwu and Oseh, (2009). In the study, 1.50 % was recorded for unparboiled paddy and 2.028 to 2.39 % range were recorded for the same variety of rice parboiled at different temperatures of 80^{0}C, 100^{0}C and 120^{0}C (Chukwu and Oseh, 2009). The effect of soaking time and storage duration were more felt compared to drying temperature and parboiling temperature in this study.

4.2.5. Crude fibre content of *Ofada* rice

The minimum and maximum values of *Ofada* rice as affected by storage duration and processing condition were 0.12 and 0.37 respectively. The lack of fit is significant which showed that mean is the best predictor of the effect of processing conditions on crude fibre of *Ofada* rice. Minimum value was obtained from paddy stored for 9 months and processed by soaking of paddy for 5 days, parboiling for 80 ^{0}C, and drying at 70^{0}C while maximum crude fibre was from paddy stored for 1 month, soaked for 1 day, parboiled at 120^{0}C and dried at 70^{0}C. The R^2, adjusted $R^{2,}$

predicted R^2 and adequate precision of the model were presented (Table 4.6). The coefficient of the model is presented (Table 4.7). The response surface graphs for the effects of processing conditions on crude fibre of *Ofada* rice were presented (Figs. 4.79 – 4.84).

The result presented in Table 4.5 has shown that storage duration, soaking time and parboiling temperature affect crude fibre quality of processed rice. The results obtained for crude fibre in this study were low compare with data recorded by Oko *et al.*,(2012) (1 %); Ibukun (2008) (1.02-1.76 %) and Sareepuang *et al.*, 2008 (1.79±0.04 %). According to Ebuehi and Oyewole (2007) soaking significantly increases crude fibre content of rice which is importantin order to maintain the digestive system healthy and functional. A steady increase in drying temperature improves crude fibre while the opposite trend was observed for storage duration.

4.2.6. Carbohydrate content of *Ofada* rice

The carbohydrate content of the processed rice ranged from 78.58 to 84 35% with average value at 80.60 %. There were significant differences ($p < 0.05$) in the results of carbohydrate as a result of variation in processing conditions and storage. The highest value (84.55%) was obtained at 9 month storage duration, 5 days of soaking, 120^0C parboiling temperature, and 70^0C drying temperature and while the least amount (78.58%) was reported at 1 (one) month storage duration, 1 (one) day soaking, 120^0C parboiling temperature,and 30^0C drying temperature. The values for R^2, adjusted $R^{2,}$ predicted R^2 and adequate precision of the model were presented (Table 4.6). The coefficient of the model is presented (Table 4.7).

Extrapolating from the Table 4.7, soaking at minimum number of days showed high percentage of carbohydrate while the extremes parboiling temperature(low and high temperature) also favoured increase in carbohydrate content. However, steady increase in drying temperature and increase in storage duration were also found to be proportional to the increase concentration of carbohydratein *Ofada rice*.

Effect of parboiling on physico-chemical qualities of two local rice varieties from South-West, Nigeria investigated by *Otegbayo et al*., (2001), revealed that parboiling as a process increases the carbohydrate content of rice when compared to non parboiled rice. According to Ituen and Ukpakha (2011), soaking of rice at 80^0C hot water for 3 h, and steam parboiling for 20 min was analyzed as optimum processing condition with total carbohydrate of 81.30 % compared to the traditional method that gives 77.4 %.

Adeniran *et al*., (2012), recorded a relative low carbohydrate as a result of using specific microbes for soaking/fermenting paddy rice. Therefore, ithas shown that processing conditions and aging could affect the carbohydrate composition of rice.

4.2.7. Free fatty acid content of *Ofada* rice

There were no significant differences ($p > 0.05$) in the result obtained for fatty acid contents of *Ofada* rice. The fatty acid ranged from 1.23 to 4.78 % calculated as oleic acid. The mean value was 2.29 % with the highest amount obtained at one month of paddy storage, 5 days soaking period, 80^0C parboiling, and 30^0C drying temperature; however lowest fatty acid was recorded at the same storage duration followed by soaking for 5 days, parboiling at 120^0C, and drying at 70^0C. The values for R^2, adjusted $R^{2,}$ predicted R^2 and adequate precision of the model were presented in Table 4.6. The coefficient of the model showing the effect of processing parameters and storage duration on free fatty acid in *Ofada* rice is presented (Table 4.7).

The results of free fatty acid described the presence of peroxides which are responsible for auto-oxidation, hence, rancidity of a product. According to Bryant *et al*., (2011), various form of unsaturated fatty acids have been detected in aromatic and non aromatic rice varieties. These fatty acids act as antifungi and increase with ageing. The result depicted reduction in free fatty acid with increase in soaking time and parboiling temperaturewhile increase in drying temperature also steadily lowered the fatty acid content of*Ofada* rice. Lipase an enzyme that speeds up lipolitic reaction is affected by high temperature or rendered inactive at high temperature (Fennema, 1996).

Fatty acids are major components of all lipids classes but must occur as acyl esters of glycerol, which are non polar lipids (Inching, 2007). According to Lee *et al*., (1965) as reported by Kabirullah and Rahman (2001), that storage time has effect on rice fatty acids which increases with storage time. The various processing operations involved in the processing might have distorted reactions that lead to the production of free fatty acids. Storage of raw brown rice for 6 month at 28.30 ^{0}C did not revealed significant change during storage but reduction in fatty acid as a result of parboiling process (Biswas, 1987).

4.2.8. Metabolizable Energy of *Ofada* rice

The metabolizable energy ranged from 367.18 to 400.40 kcal/100g. There were significant differences at ($p<0.05$) based on the effect of the processing conditions and storage duration. The values for R^2, adjusted $R^{2,}$ predicted R^2 and adequate precision for the model on effect of processing parameters and storage on metabolizable energy on of *Ofada* rice and coefficient of the model were presented in Table 4.6 and 4.7 respectively.

The interaction between the soaking time and storage temperature produced maximum effect on metabolizable energy (372.381 – 398.749 kcal/ 100g) followed by the parboiling and storage duration. Considering the effect of individual factor on metabolizable energy, metabolizable energy relatively reduced with increase in soaking time. There exist a slight increase in metabolizable energy with steady increase in parboiling temperature and the graph showing the effect of drying temperature is hyperbolic with the highest metabolizable energy relatively at centre while elongation of storage duration favoured increase in metabolizable energy. The energy that remains after accounting for the important losses in animal is known as metabolizable energy (FAO, 2002). The average metabolizable energy for rice (381.2 kcal/100g) is closely related to that of maize (389.1 kcal/100 g) (Li *et al.*, 2010).

4.2.9. Amylose content of *Ofada* rice

Amylose content is considered the single most important characteristic for predicting rice cooking and processing behaviour (Juliano, 1985; Lii *et al.*, 1996). The total amylose of the milled rice flour was in the range 18.12 – 26.54 % with average at 22.05 %. There were significant differences ($p < 0.05$) in the result in relation to the processing conditions and the storage duration. The highest amount of amylose was obtained at one month storage with processing conditions of 5 days soaking period, 80 ^{0}C parboiling temperature, and 30 ^{0}C drying temperature while the lowest was at 5 month storage duration, 3 days soaking period, 120 ^{0}C parboiling temperature, and 50 ^{0}C drying temperature.

The lack of fit test for the model is not significant which is good for the fitness of the model. The values for R^2, adjusted R^2, predicted R^2 and adequate precision for the model were presented (Table 4.6) and coefficient of quadratic model is also presented (Table 4.7). Response surface graphs showing the effect of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temp and drying temperature, parboiling and storage duration, drying temperature and storage duration on amylose content of *Ofada* rice were presented (Figs.4.49 – 4.54).

Interactions between the drying temperature and storage duration showed the highest range of amylose content (23.1425 – 28.9323 %) (Fig.4.54) preceded by parboiling and drying temperature (21.0078 – 27.1963 %) (Fig.4.52). Soaking time and parboiling temperature produced the least effect (Fig.4.39). Considering the individual processing operations as described in the graphs, the plot between the soaking time and parboiling temperature was concave with minimum values of amylose produced at the two extremes (1 and 5 soaking time; 80 °C and 120 °C parboiling temperatures) but soaking time gave a sharp concave while parboiling curve was relatively extended.

The high coefficient of soaking (S) and parboiling temperature (P) supported the finding. The opposite were the cases of drying temperature and storage duration with inverted concave and the mid values producing the highest amount of amylose. The overview of the results revealed a relative decrease in the amylose content during storage which latter showed an increase. This might be in agreement with the statement that amount of amylose soluble in boiling – water decreases during rice storage (Zhou*et al.*, 2001). Therefore, a decrease in the loss of soluble amylose during the course of storage increased the total amylose content of the milled rice.

Zhou *et al.*, (2001), reported the importance of percentage insoluble amylose, calculated from total amylose and soluble amylose at 100 ^{0}C, as a determination of rice quality. In some Nigeria local varieties as reported by Otegbayo *et al.*, (2001), parboiling at 120 ^{0}C produced 22.39 % amylose content while the result for non parboiled was 28.58 % in non parboiled. The result indicated that parboiling as a processing operation reduced amylose content of rice.

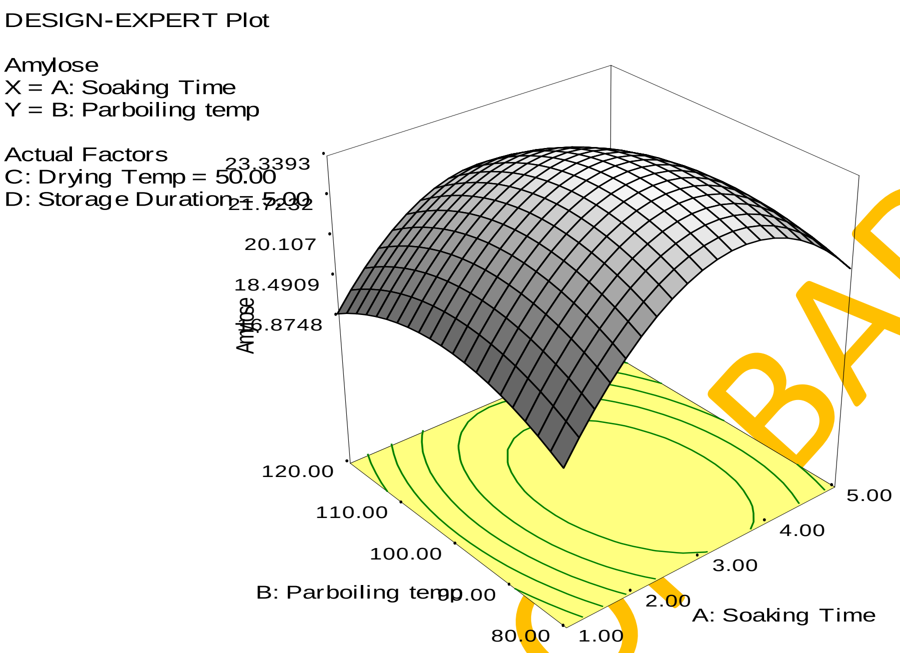

Fig.4.49 : Effect of soaking time and parboiling temperature on amylose content

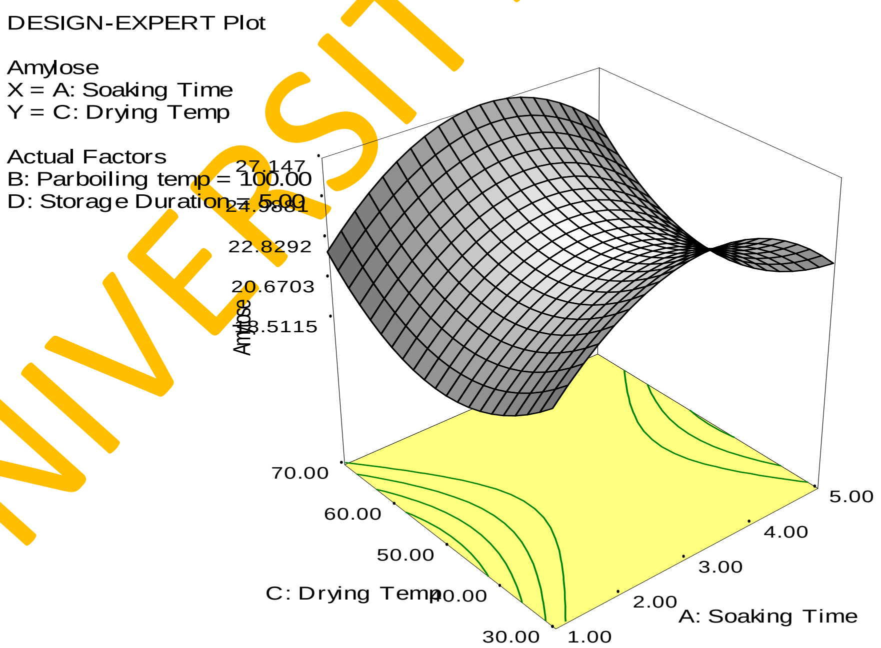

Fig.4.50: Effect of soaking time and drying temperature on amylose content

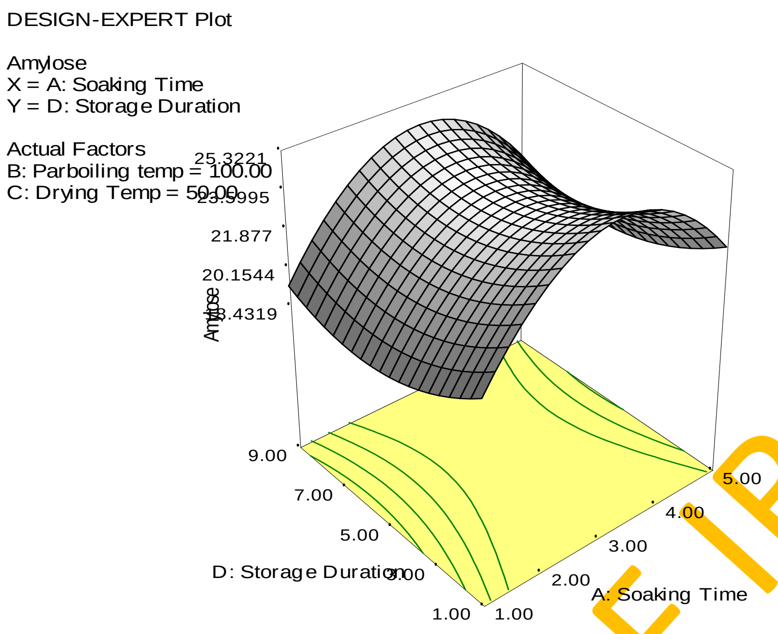

Fig.4.51: Effect of soaking time and storage duration on amylose content

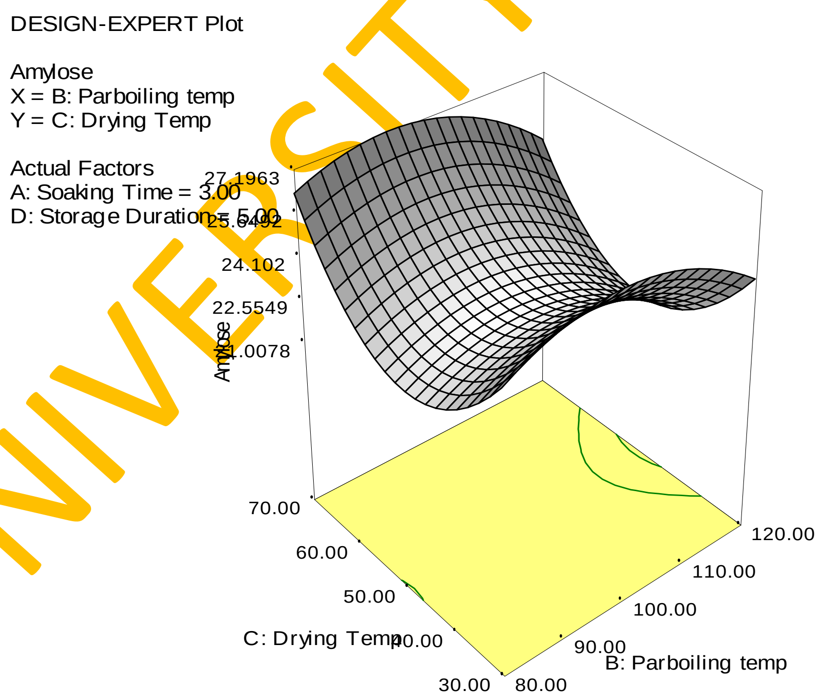

Fig.4.52: Effect of parboiling temperature and drying temperature on amylose content

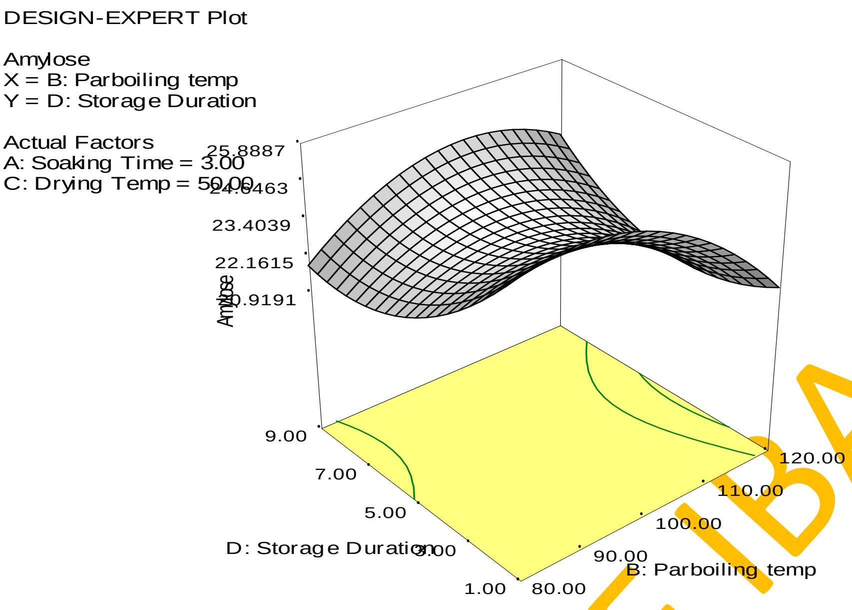

Fig.4.53: Effect of parboiling temperature and storage duration on amylose content

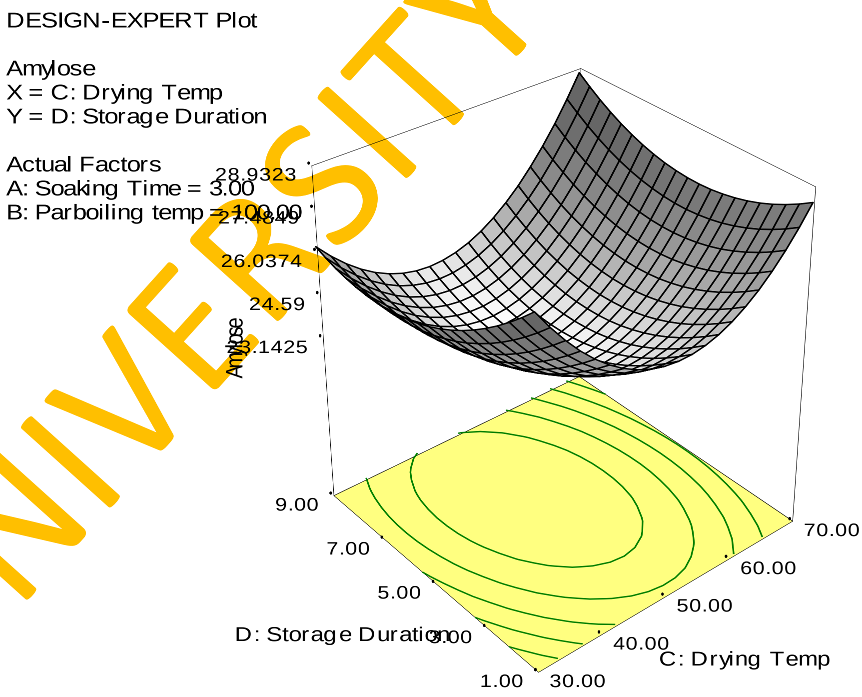

Fig.4.54: Effect of drying temperature and storage duration on amylose content

4.2.9 Optimisation of chemical qualities of *Ofada* rice

The optimisation of best processing conditions and storage duration for *Ofada* rice was assessed based on the following parameters; minimum moisture content, maximum protein, minimum fat, maximum carbohydrate, maximum crude fibre, minimum fatty acid, maximum metabolizable energy and maximum amylose content. The result of the optimisation is presented in Table 4.8.

The result from the optimisation process revealed that the best solution was achieved by storage of paddy for 9 months, soaking time of 1 day:8 h, parboiling at 120°C, and drying at 30.00 °C drying to yield 4.97% moisture, 9.59% protein, 0.95 % fat, 83.19% carbohydrate, 0.16% crude fibre, 1.31 % free fatty acid, 392.84kcal/100g metabolizable energy and 24.20 % amylose.

Table 4.8:Predicted solutions for optimisation of chemical qualities of *Ofada* rice

Number	Soaking Time,day	Parboiling temp.°C	Drying Temp.°C	Storage Duration,month	Moisture %	Protein %	Ether Extract,%	Carbohydrate %	CrudeFibre %	Fatty Acid %	Metabolisable Energy,kcal/100g	Amylose %	Desirability
1	1.82	120.00	30.00	9.00	4.9725	9.58603	0.94677	83.6928	0.155862	1.30539	392.835	24.2024	0.8066562
2	1.68	119.98	30.00	9.00	4.84626	9.6058	0.97705	83.759	0.154094	1.30805	393.299	23.8616	0.80632714
3	4.15	120.00	30.83	8.98	4.98681	9.75604	1.04324	83.2549	0.154061	1.4385	391.44	23.9923	0.80398385
4	3.34	120.00	30.00	8.66	5.81632	9.61348	0.893895	82.8659	0.16583	1.3135	389.097	25.2019	0.78551424
5	4.67	120.00	32.79	9.00	4.35017	9.90868	1.22723	83.3952	0.143002	1.55988	392.837	22.0498	0.7834054
6	4.93	102.81	30.00	9.00	5.56456	9.80145	1.48155	82.4422	0.169972	1.94014	390.416	23.1367	0.7277408
7	5.00	97.02	30.37	9.00	5.74901	9.86962	1.60451	82.1992	0.1655	2.12426	390.519	22.7199	0.70984563
8	3.11	80.02	30.00	9.00	6.89019	9.9226	1.83454	81.3144	0.180345	3.01847	392.9	23.7788	0.6564669
9	2.07	120.00	61.30	8.80	5.85989	8.9626	1.58974	83.0546	0.165049	2.34876	392.499	23.6568	0.63139189
10	5.00	83.18	67.33	9.00	6.64297	9.52788	1.61462	81.4576	0.0736284	2.34623	379.076	23.8175	0.62970325

4.3 Cooking properties of *Ofada* rice

The results of cooking properties(cooking time, water uptake ratio, elongation and solid loss) of *Ofada* rice as affected by processing conditions and storage is presented (Table 4.9).

4.3.1 Cooking time

The cooking time of *Ofada* rice was shown in Table 4.9. The minimum and maximum cooking time values were 15 and 44 min respectively while the average value was 28.28min. There exist significant differences ($p < 0.05$) in the cooking time as affected by the processing parameters. The maximum cooking time was obtained at 9 months storage duration, 1 (one) day soaking time, 120^{0}C parboiling temperature, and 50^{0}C drying temperature while the minimum cooking time was at 1 month storage of paddy, 1 (one) day of soaking, 80^{0}C parboiling temperature, and 70^{0}C drying temperature. The R^2, Adjusted R^2, predicted $R^2$and adequate precision of the model were presented in Table 4.10 and coefficient of the model was also presented (Table 4.11).The coefficient ofpredicted R^2revealed that the model was good for the prediction of effect of processing parameters and storage on cooking time of *Ofada* rice.

Response surface graphs showing interactions of the effects of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temperature and drying temperature, parboiling temperature and storage duration, drying temperature and storage duration on cooking time of *Ofada* rice were presented (Figs.4.55 – 4.60). The cooking time range of parboiled rice obtained in this experiment was high (15 - 44min) compared with 10-25 min reported by Adeyemi *et al.*, (1986). However, Otegbayo *et al.*, (2001), revealed cooking time between 52-56 min which is higher than the result obtained in this study. Research works from different backgrounds have shown that parboiling increased cooking time of rice (Saeed *et al.*, 2011; Otegbayo *et al.*, 2001). The removal of bran layers that are richer in proteins and lipids probably facilitates water migration into rice kernels during cooking thereby, reducing the cooking time (Saleh and Meullent, 2008).

The present result showed that soaking significantly reduced cooking time in agreement with Sareepuang *et al.*, (2008). Parboiling is another essential factor which affected the cooking time. An increased in parboiling temperature also increased cooking time as shown in the response surface plots (Figs.4.55, 4.58 and 4.59). The result is in agreement with the findings of *Saeed et al.*, (2011), that parboiling increases cooking time in milled rice but indicated that the opposite was the trend with brown rice. The degree of gelatinisation of the starch to form hard gels may be one of the factors responsible for the data obtained. Drying at relatively mild temperature i.e (50 ^{0}C) had the lowest cooking time (Figs.4.56, 4.58 and 4.60) while cooking time also increased with storage duration (Figs.4.57, 4.59 and 4.60).

4.3.2. Water uptake ratio

The data obtained for water uptake ratio revealed significant differences at $p < 0.05$. The water uptake ratio ranged between 2.5 – 4.86 with average ratio at 3.65. The lack of fit test was not significant which is good for the model fitness. The R^2, adjusted R^2, predicted R^2, and adequate precision were presented (Table 4.10). The coefficient of the model was also presented (Table 4.11). Response surface graphs showing interactions between effects of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling and drying temperature, parboiling and storage duration, drying temperature and storage duration on water uptake ratio were presented (Figs. 4.61– 4.66).

Considering the effects of interactions and the individual factors as given in response plots, soaking time relatively showed a concave upward curve with extremes (highest and lowest point) producing high water uptake ratio (Figs. 4.61, 4.62 and 4.63). The effect was opposite to the drying temperature that produced concave downward curves with the average variable temperature producing the highest water

Table 4.9: Cooking properties of *Ofada* rice

Run	Soaking day	Parboiling °C	Drying °C	Storage duration month	Cooking time minute	Water uptake ratio	Solid loss %	Elongation %
1	1	120	70	1	28	2.66	1.69	6.2
2	1	80	70	1	15	3.26	4.05	7.59
3	5	80	30	5	23	4.61	4.78	9.2
4	5	80	30	1	20	3.69	4.7	6.32
5	3	80	30	9	23	4.23	2.63	9.6
6	5	80	50	5	19	4.39	5.1	11.76
7	1	120	30	5	38	3.46	2.99	9.23
8	5	80	70	1	17	3.2	4.09	6.77
9	3	120	70	9	39	3.43	3.21	9.64
10	3	120	50	5	37	3.49	3.6	9.8
11	5	120	30	9	42	3.38	3.28	9.85
12	1	100	50	5	26	3.98	4.16	10
13	3	120	70	5	39	3.3	2.94	9.9
14	1	100	50	9	29	4.01	4.55	9.55
15	5	120	50	9	44	3.86	2.82	9.3
16	1	120	70	1	25	2.84	3.58	7.52
17	3	100	50	5	35	3.99	3.37	8.8
18	5	100	50	5	32	3.76	3.99	7.71
19	1	80	30	1	16	3.27	5.01	8.45
20	1	120	30	1	26	2.51	1.53	8
21	5	100	30	9	34	4.08	4.27	9.6
22	1	80	70	5	27	4.29	3.9	12.5
23	5	80	70	9	25	4.86	3.51	9.9
24	1	80	30	9	21	4.2	2.65	10.7
25	1	120	30	1	27	2.56	1.47	8.09

Table 4.10: ANOVA of regression of cooking properties as a function of storage and processing conditions

Parameters	p-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Cooking time (min)	<0.0001	0.9586	0.9006	0.366	13.412
Water uptake ratio	<0.0001	0.987	0.9687	0.9123	26.927
Solid loss	0.0068	0.8781	0.7075	-0.0449	7.932
Elongation (mm)	3.67	0.8371	0.609	-0.8423	7.848

Table 4.11: Coefficient of model on effect of storage and processing on cooking quality of *Ofada* rice

	Cooking time min	Water uptake ratio	Solid loss %	Elongation mm
Intercept	-25.98	8.01	3.19	23.03
S	1.75	-0.43	0.66	1.11
P	0.68	-0.1	0.11	-0.42
D	-0.32	0.05	-0.12	0.08
T	2	0.47	-0.44	1.35
S^2	0.28	0.04	-0.19	-0.02
P^2	$-1.57 x 10^{-3}$	$3.97 x 10^{-4}$	$-1.12 x 10^{-3}$	$2.53 x 10^{-3}$
D^2	$5.01 x 10^{-3}$	$5.61 x 10^{-4}$	$4.92 x 10^{-4}$	$1.88 x 10^{-4}$
T^2	-0.29	-0.02	-0.02	-0.09
SP	-0.03	$2.07 x 10^{-3}$	$5.59 x 10^{-3}$	-0.02
SD	$-2.62 x 10^{-3}$	$1.25 x 10^{-3}$	$2.34 x 10^{-3}$	0.01
ST	-0.18	-0.02	-0.04	$2.76 x 10^{-3}$
PD	$-1.44 x 10^{-3}$	$-3.41 x 10^{-5}$	$4.34 x 10^{-4}$	$-1.17 x 10^{-3}$
PT	0.03	$-7.94 x 10^{-4}$	$7.22 x 10^{-3}$	$-8.68 x 10^{-4}$
DT	$-2.77 x 10^{-3}$	$7.0 x 10^{-4}$	$1.23 x 10^{-3}$	$-3.92 x 10^{-5}$

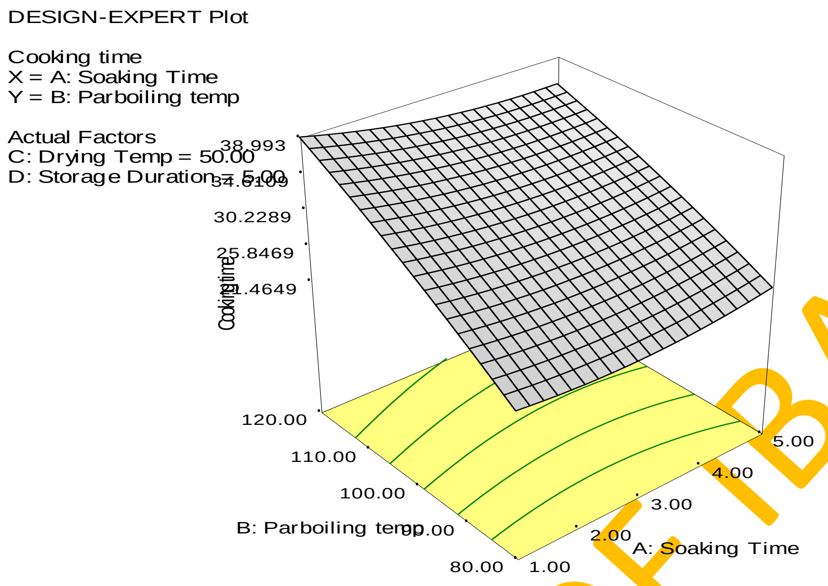

Fig.4.55: Effect of soaking time and parboiling temperature on cooking time

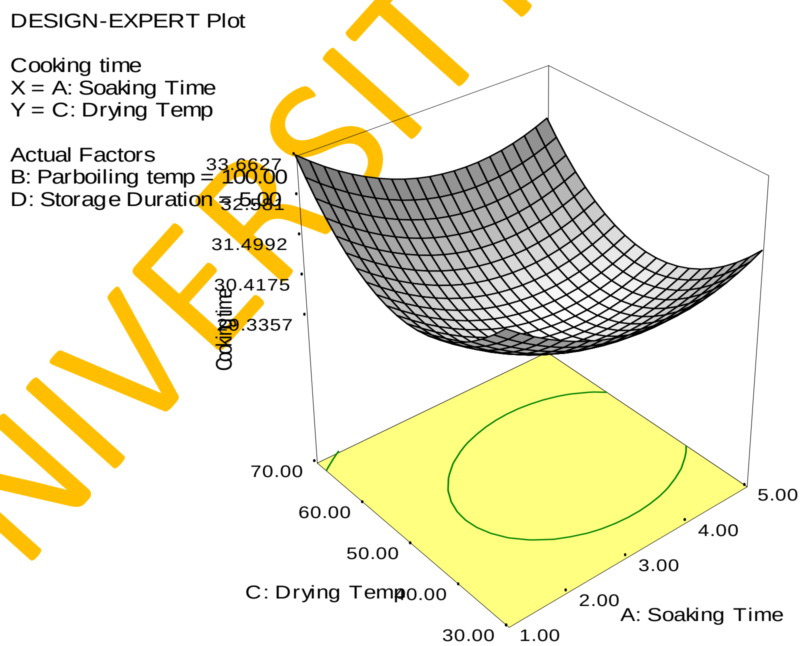

Fig.4.56: Effect of soaking time and drying temperature on cooking time

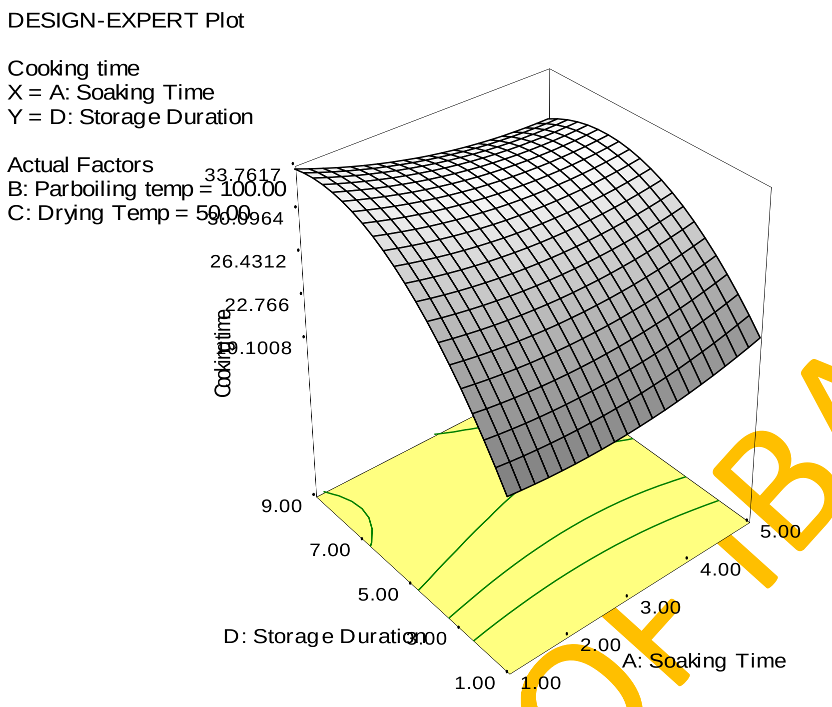

Fig.4.57: Effect of soaking time and storage duration on cooking time

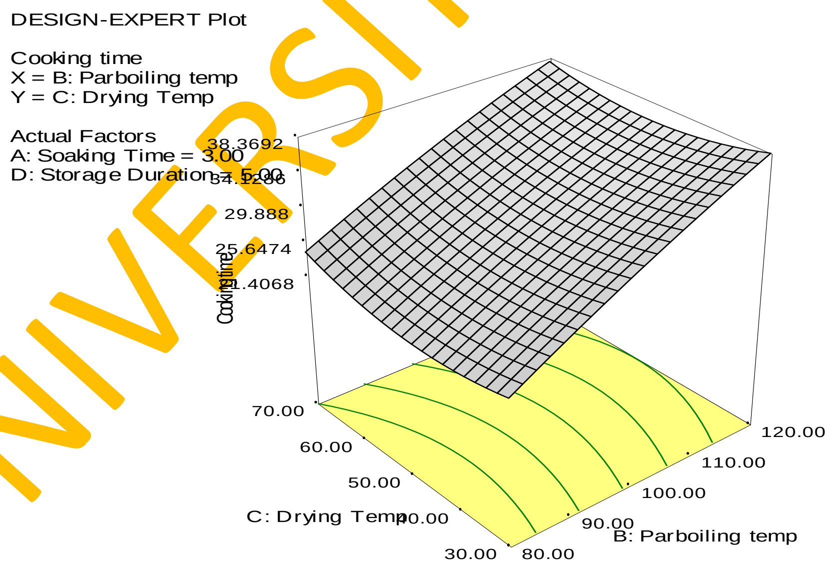

Fig.4.58: Effect of parboiling and drying temperature on cooking time

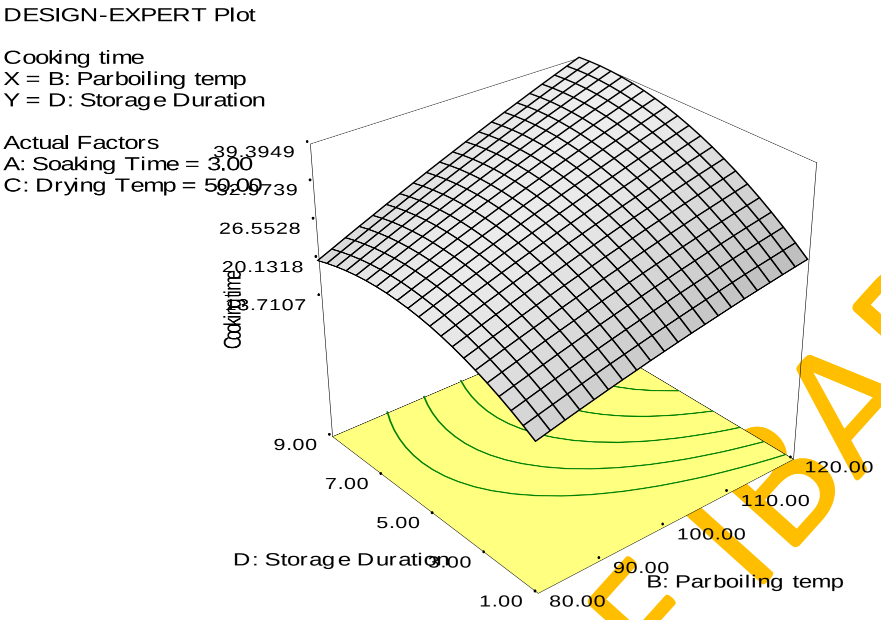

Fig.4.59: Effect of parboiling temperature and storage duration on cooking time

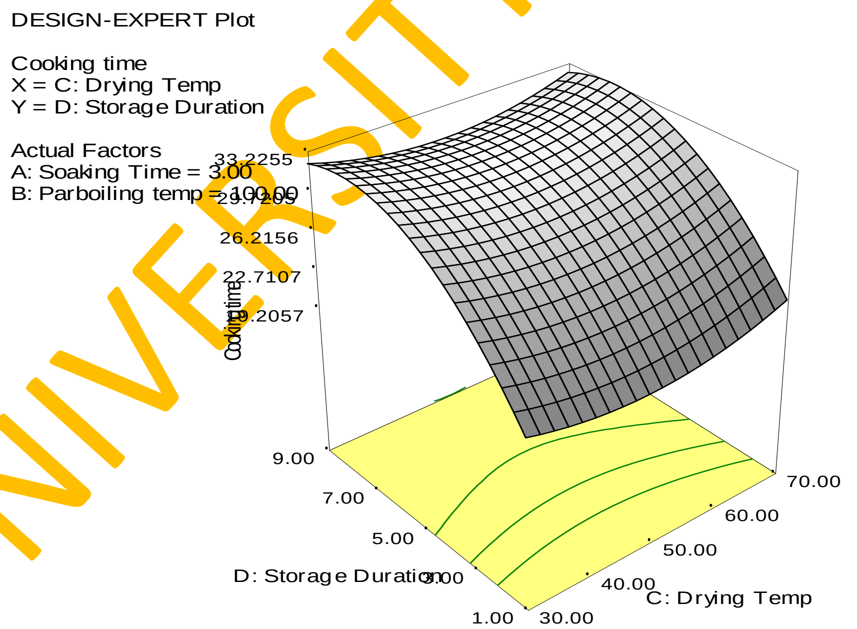

Fig.4.60: Effect of drying temperature and storage duration on cooking time

uptake ratio (Figs.4.62, 4.64, and 4.66). The parboiling temperature produced downward curve from the least to the highest with the water uptake ratio reducing withincrease in parboiling temperature (Figs.4.61, 4.64 and 4.65), but increase in storage duration is directly proportional to water uptake ratio (Figs. 4.63, 4.65 and 4.66).

The highest water uptake ratio was obtained from paddy stored for 9 months followed by soaking for 1(one) day, parboiling at 80 ^{0}C, and drying at 70 ^{0}C while the least water uptake ratio was obtained from paddy stored for 1(one) month, soaked for 1(one) day, parboiled at 120 ^{0}C and dried at 30 ^{0}C. The highest water uptake ratio obtained at the least parboiling temperature (80 ^{0}C) was in line with the explanation Biswa, (1987), that parboiled milled rice of low gelatinization temperature varieties absorbed higher water content than intermediate i.e gelatinization temperature varieties at room temperature. This was not in line with the discovery of Melidizadeh and Zomorodian, (2009), which stated that high gelatinization temperature meaning higher water absorption. Although the quality of the starch (amylose: amylopatin ration) and the varietal variation could also contribute to the water uptake ratio.

The result (1.14-3.30) for water uptake ratio obtained in the experiment carried out by Oko *et al.*, (2012) on different varieties of rice in Nigeria was not comparable with the values reported in the present study. The various processing conditions might have initiated the variations. Amylose content was reported by Frei and Becker (2003) to affect the water uptake of rice. Increase in amylose content improves water uptake. Minimum drying temperature gave low water uptake. It is worthy to note that high water ratio affects the palatability of the cooked rice negatively. The interactions of the processing conditions have favoured increase in water uptake which translate to more gain for rice vendors in term of volume better than result gotten from new breeds of rice (Nerica) which was recorded to range between 2.02 to 2.36 (*Fofana et al.*, 2011).

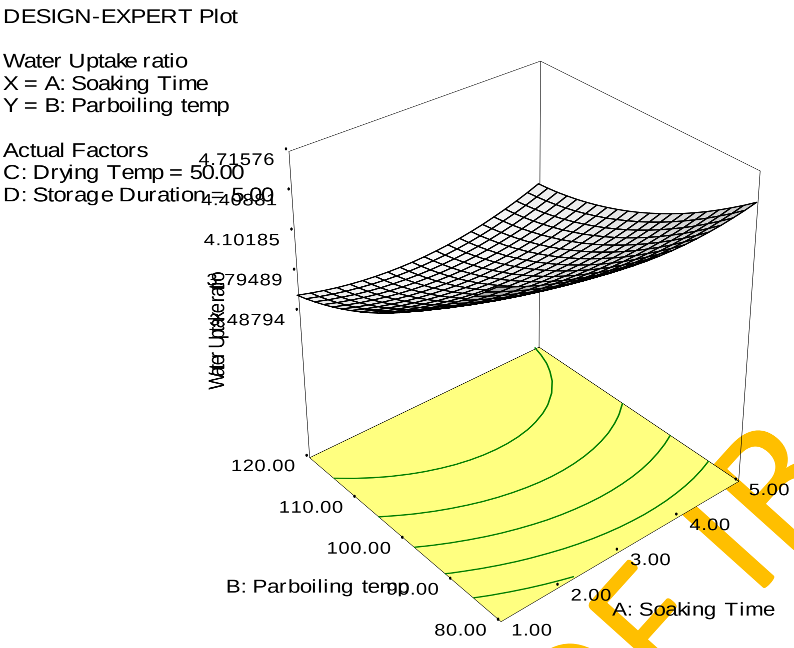

Fig.4.61: Effect of soaking time and parboiling temperature on water uptake ratio

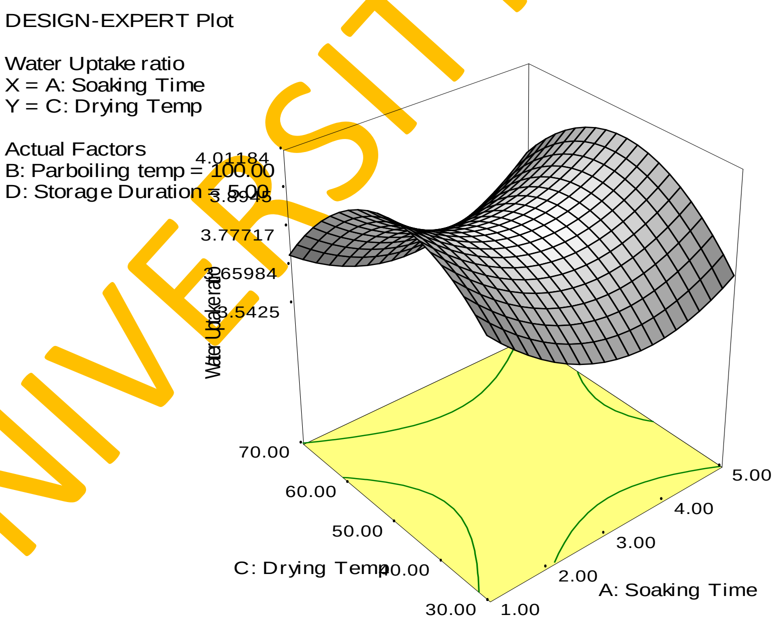

Fig.4.62: Effect of soaking time and drying temperature on water uptake ratio

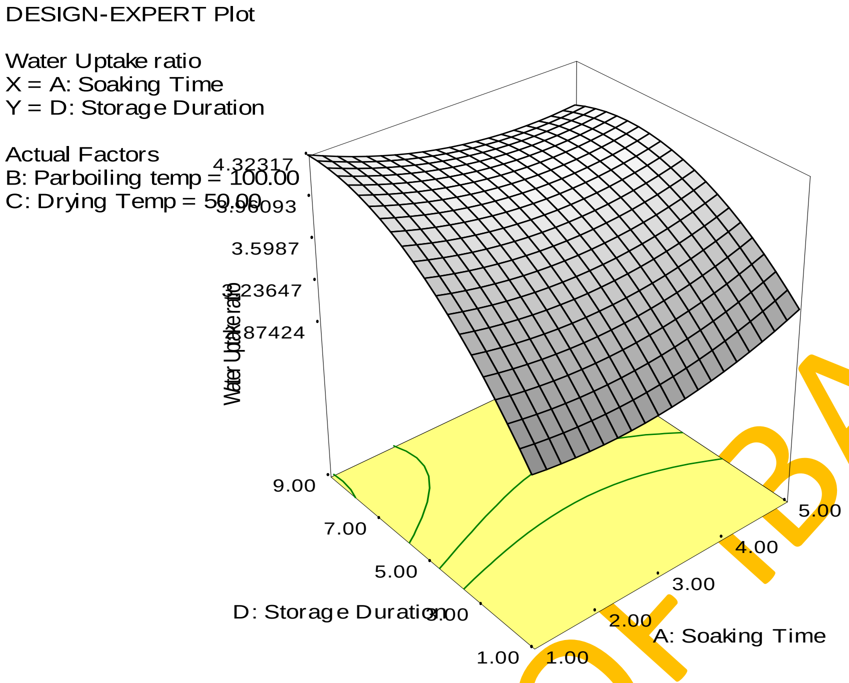

Fig.4.63: Effect of soaking time and storage duration on water uptake ratio

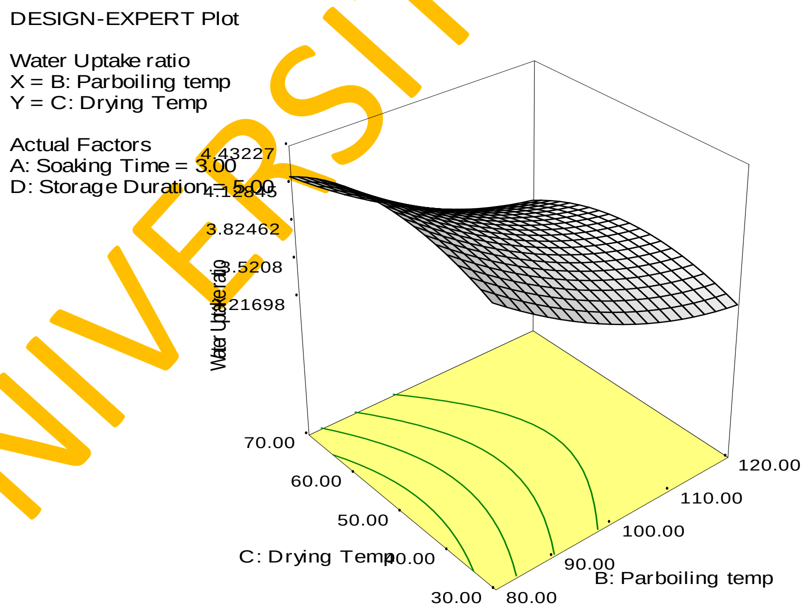

Fig.4.64: Effect of soaking time and storage duration on water uptake ratio

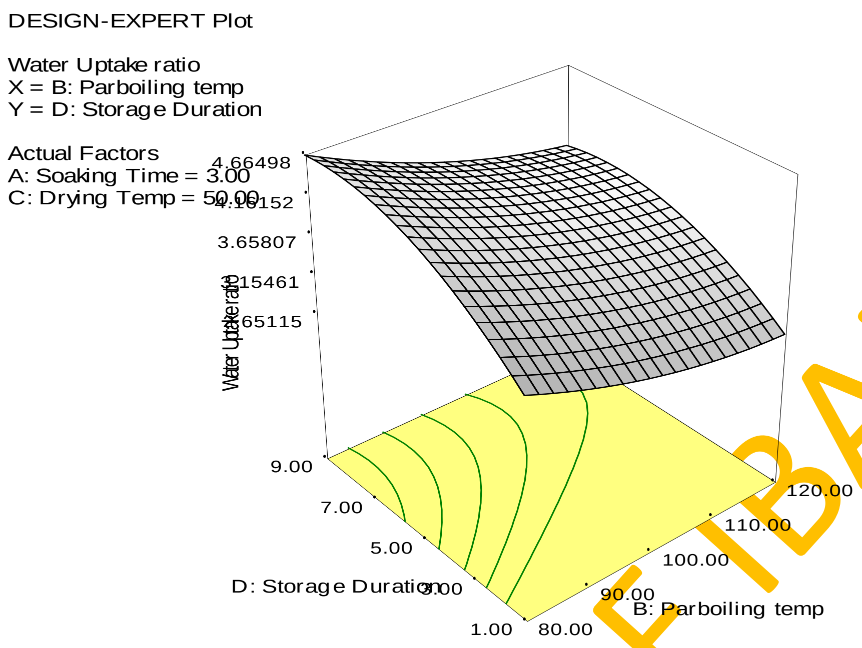

Fig.4.65: Effect of parboiling temperature and storage duration on water uptake ratio

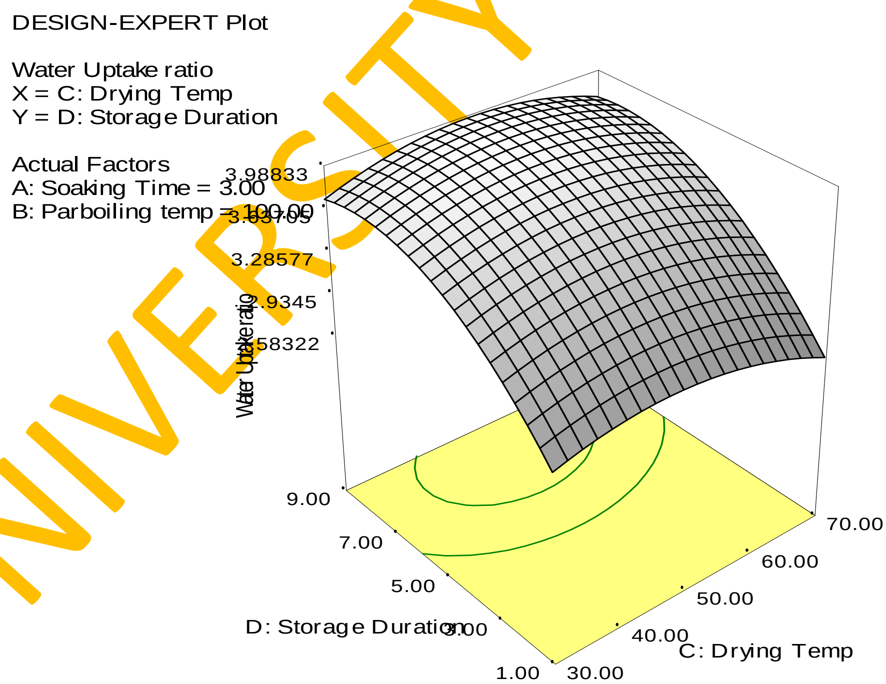

Fig.4.66: Effect of drying temperature and storage duration on water uptake ratio

4.3.3. Solid Loss

The percentage solid loss from *Ofada* rice ranged from 1.47 to 5.10 %. There were significant differences ($p < 0.05$) in the percentage solid loss as a result of variations in the processing parameters and storage duration. The “lack of fit F-value” of 1.30 implied the lack of fit is not significant; this value justified the fitness of the model to describe the effect of processing conditions on solid loss of *Ofada*. The R^2, adjusted R^2, predicted R^2, and adequate precision were presented (Table 4.10). The high value of R^2 (0.8452) and low standard deviation of 0.65 accorded the fitness of the model. The coefficient of the model is presented (Table 4.11). Effect of soaking time (S) and parboiling temperature (P)were found to have more positive effect at decreasing solid loss of milled rice.

The lowest solid loss (1.47 %) was from paddy stored for one month, soaked for one day, parboiled at 120 ^{0}C, and dried at 30 ^{0}C while the highest solid loss (5.10 %) was from paddy stored for one month, soaked for 5 days, parboiled at 80 ^{0}C, and dried at 30 ^{0}C. The trend of the result revealed that solid loss decreased with increase in parboiling temperature. This is supported by the Sareepuang *et al.*, (2008), that parboiling caused stronger structure of rice starch as a result of gelatinization. Solids in cooking water (loss in solids) affect the stability of the cooked rice (Juliano *et al.*, 1982). The variation in values may be as a result of the variation in the rice consistency, due to bursting of the grains during and after cooking, as they were subjected to different processing conditions (Oko *et al.*, 2012).

It was also discovered that most physico-chemical characteristics i.e amylose, amylopectin, gel consistency, and gelatinization temperature were significantly correlated either positively or negatively with cooking qualities traits i.e solid loss, grain elongation and so on (Oko *et al.*, 2012). The effect of drying temperature is relatively stable while the solid loss shown a slight increase with storage duration.

4.3.4. Elongation

The longitudinal increase in rice after cooking was from 6.20 to 12.50 mm. The processing conditions insignificantly affected the elongation of the rice ($p \leq 0.05$). The R^2, adjusted R^2, predicted R^2, and adequate precision and coefficient of the model were presented in Table 4.9 and 4.10 respectively. The value of R^2 and low standard deviation of 0.8371 and 0.96 respectively increased the degree of fitness of the model.

The result revealed that low parboiling temperature and increase in soaking time favoured grain elongation (Table 4.9). Combination of low drying temperature and low soaking time were most preferred for high elongation while increase in storage duration lead to increase in elongation. According to Ashish-Jain *et al.*, (2012), high volume expansion correlates with high amylose content.

4.3.5. Optimisation of cooking qualities of *Ofada* rice

The best solution prescribed for good cooking qualities of *Ofada* rice was based onminimum cooking time, high water uptake ratio, minimum solid loss and maximum elongation. The predicted storage and processing conditions include storage of paddy for 9 months, soaking for 5 days, parboiling at 80°C, and drying at 55°C months with desirability of 0.82 to yield 20.24min cooking time, 4.54 water uptake ratio, 2.53% solid loss and 11.76mm elongation. Other relevant solutions were presented in Table 4.12.

Table 4.12**:** Predicted solutions for optimisation of cooking qualities of *Ofada* rice

Number	Soaking Time	Parboiling temp	Drying Temp	Storage Duration	Cooking time	Water Uptake ratio	Solid Loss	Elongation	Desirability	
1	5.00	80.00	55.05	9.00	20.2488	4.5362	2.52724	11.76	0.815233	Selected
2	5.00	80.17	64.53	9.00	21.5322	4.46517	2.62106	12.3362	0.809189	
3	5.00	80.00	49.61	8.85	20.2577	4.53963	2.58354	11.4836	0.800732	
4	4.98	80.00	47.70	9.00	19.925	4.5165	2.53714	11.3096	0.798182	
5	5.00	80.00	60.69	7.80	22.8109	4.56455	3.03207	12.4302	0.774529	
6	4.67	80.00	69.57	9.00	22.3019	4.38515	2.99422	12.5006	0.76714	
7	1.02	80.00	58.40	9.00	22.6601	5.04483	3.58478	9.83572	0.648864	
8	1.19	80.00	49.11	9.00	21.6819	5.04136	3.7144	9.77893	0.639147	
9	4.97	92.18	70.00	9.00	27.9762	3.96861	3.27804	10.9013	0.59867	
10	1.01	120.00	43.56	3.52	35.0883	3.33794	2.1198	9.56614	0.466827	

4.4. Mineral quality of *Ofada* rice

The result of mineral composition of *Ofada* rice as affected by storage duration and processing condition (Table 4.13).

4.4.1. Zinc composition of *Ofada* rice

The results obtained for zinc ranged from 13.00 - 42.45 mg/kg with the average value of 25.70 mg/kg (Table 4.13). There were significant differences ($p < 0.05$) in the concentrations of zinc obtained as a result of processing conditions and storage duration. The non significant lack of fit signified that the model was fit to describe the experiment. R^2-squared, Adjusted R^2, predicted R^2, and adequate precision and coefficient of the model were presented (Table 4.14 and 4.15). Coefficient of the model revealed the positive effect of processing parameters and storage duration on zinc content of *Ofada* rice. The positive coefficient of drying (D) and parboiling temperatures (P) showedthe impact of these processing conditions in relation to other conditions. Adequate precision measures the signal noise ratio and a greater than 4 is desirable which justified the value of 6.417 obtained from the experiment.

The highest concentration of zinc (42.45mg/kg) was obtained when paddy was stored for 9 months, stored for 5 days, parboiled at 80^0C and dried at 30^0C drying while the lowest (13 mg/kg) was obtained from paddy stored for 5 months followed by 1(one) day of soaking, parboiling at 120^0C, and drying at 70^0C.The concentrations of zinc obtained from this experiment were on the high side which might be associated to the variation of processing condition or the variety.

In the result presented (Table 4.13), the parboiling temperature and storage duration have more influence on the zinc concentration of *Ofada* rice. Increase in storage duration was found to be proportional to the increase in zinc concentration but opposite trend was observed with parboiling temperature. Intermediate drying temperature was found to favour maximum zinc concentration.

According to Abbas *et al*., (2011), in its investigation on the effect of processing on nutritional value of rice, highlighted that series of condition rice is subjected to from time of harvest to the time it is consumed seriously depletes it nutrient such as protein, fat, carbohydrates, mineral and vitamins. The zinc content for rough, brown and milled rice were given as 2.4, 3.3 and 18.0 mg/kg respectively while Anderson (1976) as reported by Makela *et al.,* (1998) recorded a range of 3.3 - 6.5 mg/kg in wild rice (*Zizania aquatica*) indigenous to North American. Chukwu and Oseh {2009} in the study onthe effect of various parboiling temperature on the nutritional composition of rice suggested 80°C parboiling temperature as the best for the retention of zinc in rice which was also confirmed in this experiment.

4.4.2. Iron composition of *Ofada* rice

The concentrations of iron from the experiments ranged between 24.00 – 85.00 mg/kg. The highest value of Fe was at 5 months storage duration, 1 day of soaking, 80 °C parboiling, and 30 °C drying temperature while the minimum value was at 1 month storage duration, 5 days soaking time, 120 °C parboiling temperature, and 70 °C drying temperature. There existed significant differences at $p < 0.05$ for the results of iron obtained at various processing conditions. The values of R^2, adjusted R^2, predicted R^2, and adequate precision were presented (Table 4.14). The"Lark of fit F-value" of 0.24 implied the lack of fit is not significant and this was found to be good for the fitness of the model. The coefficient of the model showing the effect of processing parameter and storage on iron concentration of *Ofada* rice is presented (Table 4.15).

The results of iron concentrations obtained in this experiment were higher compared to the report from some other authors. Martinez *et al.,* (2010); Abba *et al.,* (2011) showed values ranging from 0.03 to 0.10 mg/kg while 42 mg/kg was recorded in wild rice by Anderson (1976). The values of iron in the *Ofada* rice are enough to supplement for the deficiency of iron. Iron deficiency (ID) is the most prevalent micronutrient deficiency Worldwide, affecting mainly children under 5 and women of child bearing age living in the poorer communities of the developing world (Martinez *et al*., 2010).

Iron fortification of foods or iron supplements have traditionally been the main intervention strategies used to combat iron deficiency (ID), however, they are less suitable for the more remote rural communities in the redeveloping world (Allen *et al.*, 2006). The fortification compliance programmes in Nigeria since 1990 has not even yield expected result due to poor compliance. However, the results have shown that *Ofada* rice is a good diet for iron supplements.

Table 4.13: Mineral composition of *Ofada* rice

Number	Soaking Time,day	Parboiling temp.	Drying Temp.	Storage Duration	Zinc mg/kg	Iron mg/kg	Magnesium mg/kg	Copper mg/kg	Potassium mg/kg	Calcium mg/kg
1	5	120	70	1	18.23	24	341	28.42	25	0.3
2	1	80	70	1	32.23	35	301.22	58.09	14.15	0.5
3	1	80	30	5	37.46	85	311	2.95	18.2	0.22
4	5	80	30	1	23.85	34	279	49	10.03	0.24
5	5	80	30	9	22.76	74.98	234.25	8.04	24.68	0.29
6	3	80	50	5	31.52	45.93	275.61	3.5	26.29	0.23
7	5	120	30	5	21.98	57.07	305.89	5.05	12.88	0.39
8	1	80	70	1	30	29	307.52	42	22	0.56
9	5	120	70	9	17.52	72.98	387	10.19	22.54	0.3
10	3	120	50	5	22.98	53.74	289.66	6.8	15.02	0.33
11	3	120	30	9	19.41	47	329.18	6.5	23.61	0.43
12	5	100	50	5	32.25	58.33	308.4	5.95	18.24	0.36
13	1	120	70	5	13	58.02	247.15	4.7	15.56	0.41
14	3	100	50	9	28	66.09	296.02	9.3	29.05	0.32
15	1	120	50	9	20	27.79	365.74	4.5	15.56	0.3
16	5	120	70	1	18.06	31	344	26	30	0.28
17	1	100	50	5	28.47	76	365	10.26	16.63	0.48
18	3	100	50	5	26.63	63	299.65	21	32	0.31
19	5	80	30	1	27	30	270.06	40	10.2	0.39
20	1	120	30	1	14	45	235.66	27	13.16	0.23
21	1	100	30	9	34.87	60.55	297.63	6.65	28.98	0.3
22	5	80	70	5	25.98	57.64	288.55	6.83	10.2	0.34
23	1	80	70	9	37.76	46.9	268.22	8.35	27.9	0.62
24	5	80	30	9	42.45	28	366.16	4.6	20.93	0.35
25	1	120	30	1	16	42	276	33	13.03	0.32

Table 4.14: ANOVA of regression of mineral properties as a function of processing conditions

Parameters	P-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Zinc, mg/kg	0.023	0.8359	0.6061	0.1769	6.417
Iron, mg/kg	0.0478	0.8028	0.5267	-0.3764	5.928
Magnesium, mg/kg	0.3893	0.6284	0.1081	-1.5006	4.215
Copper, mg/kg	0.0002	0.9462	0.8709	0.4784	10.446
Potassium, mg/kg	0.0132	0.8565	0.6556	-0.67	7.264
Calcium, mg/kg	0.045	0.8057	0.5338	-1.7144	6.887

Table 4.15: Coefficient of model on effect of storage and processing parameters on mineral quality of *Ofada* rice

	Zn, mg/kg	Fe, mg/kg	Mg, mg/kg	Cu, mg/kg	K, mg/kg	Ca, mg/kg
Intercept	17.99	-154.81	715.09	-91.97	-93.02	-1.13
S	-12.28	-17.36	-130.35	6.95	5.41	7.20×10^{-3}
P	0.3	7.49	-9.68	3.47	2.51	0.03
D	1	-5.56	10.86	-0.53	-0.87	6.92×10^{-3}
T	3.08	7.05	-23.66	-20.78	2.81	2.26×10^{-3}
S^2	0.69	-0.61	11.62	-0.85	-2.11	-1.47×10^{-4}
P^2	-3.78×10^{-3}	-0.04	0.04	-0.02	-0.01	-1.47×10^{-4}
D^2	-8.84×10^{-3}	0.04	-0.13	7.75×10^{-3}	5.26×10^{-3}	1.30×10^{-4}
T^2	-0.03	-1.22	1	1.02	0.28	4.30×10^{-4}
SP	0.08	0.11	0.45	5.38×10^{-3}	0.07	4.58×10^{-4}
SD	1.51×10^{-3}	0.1	0.35	-0.07	6.7×10^{-3}	1.40×10^{-3}
ST	-0.1	0.92	0.56	0.23	-0.07	-9.64×10^{-4}
PD	-1.22×10^{-3}	0.01	0.01	-2.44×10^{-4}	4.77×10^{-3}	-1.22×10^{-4}
PT	-0.01	9.29×10^{-3}	0.33	0.05	-0.04	2.30×10^{-5}
DT	-0.01	0.08	-0.16	0.01	-0.02	3.96×10^{-3}

4.4.3 Magnesium composition of *Ofada* rice

Magnesium is one of the major elements in rice and the results of magnesium concentrations in *Ofada* rice obtained from the experiment as affected by storage duration and processing conditions ranged from 234.25 to 387.0 mg/kg. However, at the different levels of processing conditions no significant difference ($p>0.05$) were found in concentration of magnesium obtained from the experiment.

The highest amount of Mg was recorded at 9 months of storage duration, 5 days of soaking, 120^{0}C parboiling, and 70^{0}C drying temperature whilethe least concentration of Mg was derived from paddy stored for 9 months, stored for 5 days, parboiled at 80^{0}C, and dried at 30^{0}C. The "Lack of Fit F-value" of 0.55 implied the lack of fit was not significant. Non significant lack of Fit is recommended and good for the model. The values of R^2, Adjusted R^2, predicted R^2, and adequate precision and coefficient of the models were presented (Table 4.13 and 4.14).

The magnesium contents in wild rice and polished white rice are 80 -1 61 and 28 mg/100g respectively (Makela *et al.*, 1998). The results were related to some of the Mg concentration obtained in this work. Judging by the recommendation of magnesium intake by Food and Nutrition Board, (1997), the recommended daily intake of magnesium can be met with only consumption of *Ofada* rice. An adult female only require 310 – 320 mg/day and between 400 – 420 mg/day is recorded for adult males while the requirement for pregnant women and children are lesser. The major functions of magnesium include contraction and relaxation of muscles, production and transportation of energy and production of protein while its deficiency can lead to hyper-excitability, sleepiness, and weakness of the muscle.

4.4.4. Copper composition of *Ofada* rice

The concentration of cupper ranged between 2.95 and 58.09 mg/kg with the mean value of 17.15. The model F-value of 12.56 implied the model was significant and the highest concentration of copper was obtained at the lowest soaking time (1 day), 80 °C parboiling temperature, 70 °C drying temperature and one (1) month storage duration while the minimum value was also obtained at the same least levels of soaking and parboiling but 30^0C drying temperature and 5 months of storage.

The values of R^2, Adjusted R^2, predicted R^2, and adequate precision were presented in Table 4.14. The value of 10.446 adequate precision indicates adequate signal for the model with low standard deviation favoured the model. The coefficient of the model is presented (Table4.15). Soaking time (S) and parboiling temperature (P) were found to be the key processing unit operations that majorly influenced copper concentration of *Ofada* rice. An increase in soaking time causes increase in copper retention until a peak is reached and a steady concentration maintained. However, increase in storage duration steadily reduced the copper in *Ofada* rice and the same trend was recorded with the drying temperature (Table 4.13).

Copper is an essential nutrient and have normal physiological regulatory activities in organisms (Hogstrand and Haux, 2001). The USA and Canada recently established a recommended dietary allowance (RDA) of 900 μg/day for adults while 340 μg/day for those children not exceeding 3 years, 440 μg/day for ages 4 through 8, 700 μg/day for ages 9 through 13 and 890 μg/day for ages 14 through 18 (IOM, 2001). During pregnancy and lactation, 1000 μg/day and 1300 μg/day are recommended respectively. The concentrations of copper recorded in this experiment is related to the result obtained by Anjum *et al*., (2007) on mineral composition of different rice varieties, however, a range between 0.58 and 0.92 mg/100g was documented.

4.4.5. Potassium composition of *Ofada* rice

The minimum and maximum concentrations of potassium were 10.03 and 32.00 mg/kg respectively.There exist significant differences ($p < 0.05$) in the values of potassium as affected by processing parameters and storage duration. The maximum level of potassium concentration was obtained from the paddy stored for 5 months and processed by soaking for 3 days, parboiling at 100 °C, and 50 °C drying temperature while the minimum concentration was retained in paddy stored for one month, soaked for 5 days, parboiled at 80 °C and dried at 30 °C.

The “lack of fit F-value” of 2.23 obtained from the analysis implied the lack of fit is not significant. The values of R^2, Adjusted R^2, and adequate precision and coefficient of the model were as presented in Table 4.14 and 4.15. However, the fit summary suggested the quadratic model because of the highest F-value of 4.77 for the sequent model sum of squares and the lowest F-value of 2.23 for lack of fit test.

As shown in Table 4.13 potassium levels in *Ofada* rice increased with extension of storage duration, the variations in the drying temperatures during the processing of *Ofada* rice revealed relative stability in the concentrations of potassium. Potassium is a very important mineral to the human body to build proteins, break down and use carbohydrates, build muscle, maintain normal body growth, control the electrical activity of the heart and control the acid-base balance (USDA, 2010).

4.4.6. Calcium composition of *Ofada* rice

The concentrations of calcium ranged between 0.22 to 0.62 mg/kg and 0.35 mg/kg as the mean value. The highest value of calcium was recorded at 1 day soaking, 80 ^{0}C parboiling temperature, 70 ^{0}C drying temperature and 9 months storage duration while the least value was at 1(one) day soaking, 80 ^{0}C parboiling temperature, 30 ^{0}C drying temperature and 5 months storage duration. The values of R^2, Adjusted R^2, predicted R^2, and adequate precision were presented in Table 4.14. The closeness of R^2 and Adjusted R^2 to 1 and extent of greatness of adequate precision above 4 are indicators of the degree of fitness of the model. The low standard deviation and PRESS values of 0.070 and 0.68 also classified the model for better fitness. The coefficient of the model terms of actual of factors is presented (Table 4.15).

As shown in the Table 4.13, calcium levels increased steadily with soaking time, drying temperature and storage duration. Average parboiling temperatureproduced the highest calcium. Calcium contents recorded in this experiment were lower compared to the result documented by Chukwu and Oseh, (2009) which ranged from 3.287 in unparboiled rice to between 1.612 to 3.68 mg/kg in parboiled rice with rice parboiled at 120^{0}C with highest calcium concentration.

According to Sarubin and Thomson (2007), calcium is one of the most important minerals for the human body. Calcium helps form and maintains healthy teeth and bones. Proper levels of calcium over a lifetime can help prevent osteoporosis, building strong bones and teeth, clotting blood, sending and receiving nerve signals, squeezing and relaxing muscles, releasing hormones and other chemicals and keeping a normal heartbeat. Although, a large proportion of potassium is required by adult (4.7g/day), however, the composition in *ofada* rice is also significant at attaining the daily recommendation.

4.4.7. Optimisation of mineral quality of *Ofada* rice

The result of optimization of the mineral quality of*Ofada* rice was analyzed based on the recommended daily intake allowance for adults. Therefore, maximum concentrations of potassium, magnesium, calcium; and minimum amount of zinc, copper and iron were selected. The appropriate processing conditions to achieve these were predicted (Table 4.16). Storage of paddy for 9 months followed by soaking time of one day, 8 h: 8 min, parboiling at 115.08^{0}C, and drying at 58.41^{0}C were best selected for attainment of these required quality as stated.

Table4.16: Predicted solution for the optimisation of mineral qualities of *Ofada* rice

Number	Soaking Time days	Parboiling temp °C	Drying Temp °C	Storage Duration months	Zn mg/kg	Fe mg/kg	Mg mg/kg	Cu mg/kg	K mg/kg	Ca mg/kg	Desirability	
1	1.37	115.08	58.41	9.00	21.3637	44.718	327.858	9.57569	21.8341	0.394462	0.625238209	Selected
2	3.84	119.43	39.19	9.00	22.326	43.6022	357.604	8.73483	22.5575	0.341879	0.622590512	
3	1.91	116.55	56.38	9.00	20.3653	44.5728	328.449	9.60108	23.8516	0.355805	0.621387612	
4	1.94	116.61	57.12	9.00	20.083	45.2824	326.4	9.87431	24.0925	0.357589	0.621148119	
5	3.97	120.00	47.32	9.00	21.8793	43.5603	376.16	8.01142	22.1423	0.313648	0.61031034	
6	5.00	117.29	65.95	1.00	21.0248	25.1177	344.292	29.5347	26.0264	0.300029	0.5818773	
7	5.00	117.34	65.33	1.00	21.2299	24.3749	345.872	29.4236	25.7734	0.299638	0.581876935	
8	5.00	117.69	65.37	1.00	21.1259	24.0001	346.417	29.0886	25.733	0.29764	0.581835042	
9	5.00	117.07	67.54	1.00	20.4969	27.2733	339.581	29.9543	26.7086	0.302185	0.581630076	
10	1.12	119.47	63.89	1.00	14.2583	26.4018	283.966	34.8507	20.4333	0.368705	0.530164843	

4.5. Pasting properties of *Ofada* rice

The result of pasting properties of *Ofada* rice (peak, trough, breakdown, final viscosity, setback, peak time, and pasting temperature) as affected by processing conditions and storage is presented (Table 4.17). The parameters revealed were significant at $p < 0.05$ except breakdown viscosity.Pasting is a phenomenon during rice cooking following gelatinization of rice starch, which involves swelling, exudation of molecular components from the granules and eventual total disruption of the granules (Danbaba *et al.*, 2012). The minimum and maximum range of peak, trough, breakdown, final viscosity, setback, peak time and pasting temperature were 27.33 - 1951.00 RVA, 24.17 - 1583.50 RVA, 3.17 - 210.50 RVA, 38.42 - 2898.50 RVA, 14.00 - 1315 RVA, 5.54 - 7.00 min and 49.20 - 90.35°C respectively. The values of R^2, adjusted R^2, predicted R^2, and adequate precision were presented (Table 4.18) and the coefficient of the model showing the effect of processing parameter and storage on pasting properties of *Ofada* rice is presented (Table 4.19).

The average peak viscosity was 801.17RVA. The mean value recorded in this experiment was higher than the results reported by Danbaba *et al.*,(2012; Gayin *et al.*,(2009), however, correlated with the result obtained by Patindol *et al.*, (2008). The maximum peak value was obtained in the rice sample stored for 9 months and subjected to 5days soaking period followed by parboiling at 120°C temperature, and drying temperature at 70°C while minimum peak was at 1 month storage of paddy but the same trend of processing conditions.

The variation in the peak viscosity could be attributed to storage duration since the same processing conditions were maintained. According to Katekhong and Charoenrein (2012), storage of rice influences property changes in rice; the swelling of starch granule, pasting properties and thermal properties of rice. Three months of storage is regarded as the minimum period for major changes to occur in the hardness of cooked rice (Katekhong and Charoenrein, 2012). Daniels*et al.*,(1998); Perez and Juliano (1981) reported first six weeks and first month for rapid changes to occur in stored rice respectively. The data recorded in this experiment revealed increase in peak with storage duration while the reverse was reported by Katekhong and Charoenrein, (2012).

High peak viscosity value is important in the preparation of stiff dough products such as ‘tuwo shinkafa’ which is popular among the Hausas in Nigeria. According to Danbaba *et al.*, (2012), peak viscosity is an indicative of water binding capacity and ease with which starch granules are disintegrated, and often this has been seen in correlation with the quality of final product. Starch swelling is mainly due to the activity of the amylopectin, but this can be hindered by amount of protein and amylose present in the rice (Inouchi *et al.*, 2000). The soaking period caused a gradual increase in peak value while peak viscosity diminished with elevation of parboiling temperature (Table 4.17). Increases in drying temperature and storage duration were proportional to the increase in peak viscosity.

The trough values were closed to peak viscosity except in two cases (run 4 and 18 in Table 4.13). The highest trough value of 1583.5RVA was obtained from the rice sample stored for 9 months and at the processing condition of 1day soaking time, 80°C parboiling temperature, and 70°C drying while the minimum trough (24.17 RVA) was obtained from rice sample stored for 1 month, soaked for one day, parboiled at 120°C and dried at 50°C. The trough is the minimum point at which the viscosity reaches its minimum during either heating or cooling process (Danbaba *et al.*, 2012). High trough shows a tendency of rice starch to breakdown during cooking, thus, trough values usually decreased with cooking. Breakdown viscosity describes the ability of swollen starch granules to rupture when held at high temperatures with continuous shearing (Patindol *et al.*, 2008). The breakdown viscosity ranged between 3.17 to 210.5 RVA with average value of 48.01 RVA. However, the values obtained for the breakdown viscosity were not significant ($p > 0.05$). The maximum breakdown was recorded at processing conditions of 5 days of soaking, 100 °C parboiling temperature, 50 °C drying temperature and 5 months of storage while the minimum was at storage duration of paddy for 1(one) month, 5 days of soaking, 120 °C parboiling temperature, and 70 °C drying temperature.

At high breakdown there is tendency for the rice to stick (Gayin *et al.*, 2009). In a study by Tran *et al.,* (2001), when comparing the physic-chemical properties of different rice cultivars, it was deduced from the sensory report that rice cultivar with the highest breakdown value was rated the most palatable. The least breakdown viscosity makes such rice useful for dishes involving boiled rice for the grain that do not stick together which is a typical delight of many in Nigeria. This type of dish is usually consumed with fried soup or vegetable. The response surface plots describing the interaction of processing conditions on breakdown viscosity of *Ofada* rice were presented (Figs. 4.181 - 4.186). There exist significant differences ($p < 0.05$) on the value obtained for final viscosity (Table 4.13). The final viscosity ranged from 38.42 to 2898.50 RVA with a mean value of 1184.22 RVA. Final viscosity is a parameter which gives an idea of the ability of starch to gel after cooking. It is

Table 4.17: Pasting properties of *Ofada* rice

Run	Soaking Time Day	Parboiling Temp °C	Drying Temp °C	Storage Duration Month	Peak RVU	Trough RVU	Breakdown RVU	Final viscosity RVU	Set back RVU	Peak time min	Pasting temp °C
1	5	120	70	1	28.17	24.42	3.75	38.92	14.5	6.94	49.35
2	1	80	70	1	95.58	87.67	7.92	171.33	83.67	5.9	49.3
3	1	80	30	5	770	762	8	1243	481	6.4	87.95
4	5	80	30	1	138.92	90	48.92	163.92	73.92	5.54	49.4
5	5	80	30	9	1331.5	1240	91.5	2160	920	5.93	81.1
6	3	80	50	5	1570.5	1414	156.5	2519.5	1105.5	5.77	80.3
7	5	120	30	5	633.5	606	27.5	897.5	291.5	5.77	87.18
8	1	80	70	1	102.67	94.08	8.58	177.83	83.75	6.13	49.3
9	5	120	70	9	1951	929	46.5	1391.5	462.5	6.97	85.55
10	3	120	50	5	766.5	745.5	21	1178	432.5	6.93	84.38
11	3	120	30	9	815	792	23	1162	370.5	7	85.51
12	5	100	50	5	1744.5	1534	210.5	2726.5	1192.5	5.83	79.85
13	1	120	70	5	620	592	28	915	323.5	6.9	90.18
14	3	100	50	9	1373.5	680	43.5	2347.5	1017.5	6.9	84.1
15	1	120	50	9	966.5	937.5	29	1411	473.5	5.97	81.9
16	5	120	70	1	27.33	24.17	3.17	38.42	14.25	6.94	49.3
17	1	100	50	5	646	623.5	22.5	915.5	292.5	6.97	90.35
18	3	100	50	3	693	671.4	21.6	945	273.5	6.83	89.11
19	5	80	30	1	135.92	86.75	49.17	157.83	71.08	5.57	49.4
20	1	120	30	1	33.08	32.25	6.83	46.25	14	6.97	49.2
21	1	100	30	9	1017	994	23	1558	564	6.37	84.7
22	5	80	70	5	1535	1385	150	2422.5	1037	6.37	80.7
23	1	80	70	9	1705.5	1583.5	122	2898.5	1315	6.03	81.9
24	5	80	30	9	1298.5	1224	44.5	2071.5	847.5	5.97	81.45
25	1	120	30	1	30	32.56	3.42	48.5	15.92	6.97	49.25

Table 4.18: ANOVA of regression of pasting properties as a function of processing conditions

Parameters	p-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Peak, RVA	0.0003	0.9381	0.8515	-0.3633	10.337
Trough, RVA	0.0013	0.9152	0.7966	-1.2596	8.625
Breakthrough, RVA	0.1738	0.7173	0.3216	-5.4171	5.375
Final viscosity, RVA	0.0013	0.9159	0.7981	-0.6288	8.766
Setback, RVA	0.006	0.8806	0.7134	-1.2816	7.645
Peaktime, min	0.008	0.8724	0.6938	-1.1176	6.798
Pasting temperature, °C	<0.0001	0.994	0.9855	0.9018	26.825

Table 4.19: Coefficient of model on effect of storage and processing conditions on pasting properties of *Ofada* rice

	Peak RVA	Trough RVA	Breakdown RVA	Final viscosity RVA	Setback RVA	Peak time min	Peak temp. ^0C
Intercept	719.93	1881.88	-326.75	-2537.39	-115.64	-1.52	-8.96
S	-397.38	-230.58	0.67	-7.46	19.79	0.72	1.69
P	-27.19	-84.53	-0.56	-38.34	-21.25	-0.22	1.61
D	61.34	91.42	14.77	173.3	83.71	-0.18	-1.55
T	163.73	471.52	26.2	730.3	83.71	-0.18	-1.55
S^2	35.19	52.66	6.8	29.99	11.43	-0.16	-0.5
P^2	0.13	0.5	0.62	0.35	0.18	$-1.04x10^{-3}$	$-9.16x10^{-3}$
D^2	-0.56	-0.6	-0.09	-1.16	-0.55	$1.34x10^{-3}$	0.01
T^2	-11.94	-20.81	-1.5	-21.08	-6.79	$-1.21x10^{-3}$	-1.26
SP	0.61	-6.94	-0.3	-1.47	-0.6	$-1.66x10^{-3}$	0.02
SD	3.32	1.83	0.16	2.48	0.89	$4.70x10^{-3}$	-0.03
ST	12.38	-5.13	-0.84	-7.13	-3.94	0.02	0.04
PD	-0.19	-0.35	-0.06	-0.63	-0.31	$3.78x10^{-4}$	$4.18x10^{-3}$
PT	0.33	-1.27	-0.11	-3.42	-1.96	$-1.31x10^{-3}$	$9.05x10^{-3}$
DT	2.4	0.26	0.16	1.45	0.8	$4.36x10^{-4}$	$6.42x10^{-3}$

also important in determining ability of the sample material to form gel during processing (Niba *et al.*, 2001

Highest final viscosity was recorded from paddy stored for 9 months, and subjected to 1(one) day of soaking, parboiling at 80 °C and drying at 70 °C while the least was at 1 month storage, 120°C parboiling and 70°C drying temperature. Rice with high viscosity has firm paste and increase in paste viscosity when a hot paste is cooled is governed by the tendency of the starch to undergo retrogradation.

The set back viscosity ranged from 14.00 to 1315 RVA with mean value of 470.84 RVA. There exist significant differences ($p < 0.05$) in the values obtained for the setback viscosity as presented (Table 4.13). The maximum setback was obtained from the rice sample stored for 9 months, soaked for 1 day, parboiled at 80°C and dried 70°C. Observation has shown that the same processing conditions for maximum setback were also recorded for final viscosity. The minimum setback was from 1 month storage of paddy, 1 day soaking, 120°C parboiling temperature and 30°C drying temperature. The retrogradation tendency of rice is determined by setback (Traore, 2005). Low setback is related to soft rice texture.

The minimum and maximum peak times were 5.54 and 7.00 min respectively with an average of 6.39 min and the result were also significant at $p < 0.05$. The maximum peak time was obtained from rice stored for 9(nine) months, soaked for 3 days, parboiled at 120°C and dried at 30°C while the minimum peak time was from paddy with storage duration of 1 month, 5 days of soaking, 80°C and 30°C parboiling and drying temperatures respectively. The pasting temperature recorded from the experiment were significant at $p<0.05$ and ranged from 49.20 to 90.35°C. The pasting temperature is the temperature at which viscosity start to rise. It was generally observed from the result that *Ofada* rice stored for 1 month have low pasting temperature (less than 50°C) compared to those stored for 5 and 9 months which fall within 78 and 90°C. The range of pasting temperature recorded in this experiment is similar with result documented by Eke-Ejiofor *et al.*, (2011).

Usually, pasting temperature is higher than the gelatinization temperature, which means that starch granules are gelatinized before the viscosity begins to rise and detected by the RVA. Low pasting temperature indicates faster swelling. Higher peak temperature suggests the presence of higher proportion of long amylopectin chains and would require higher temperatures to dissociate (Nweta *et al.*, 2008).

4.5.1 Optimisation of pasting properties of *Ofada* rice

Optimisation of pasting properties of *Ofada* rice is determined by the utilisation or end use. The two major end use of *Ofada* rice could be classified as either boiled rice which is the most popular mean of consumption or in the preparation of rice balls; a popular dish common in the Northern part of Nigeria in which boiled rice is mashed and moulded like balls usually eaten with soup such as okro/*Cocorus*. In the preparation of non sticky boiled rice, the requirement for the pasting optimisation include; low breakdown viscosity, least trough value and high setback viscosity while for marshy porridge; low setback, high breakdown viscosity and high trough value are required.

The best processing condition for boiled *Ofada* rice as predicted include; storage of paddy for 9 months and processing by soaking for 2 days and 19 h, parboiling at 90.42 °C, and drying at 30 °C (Table 4.20) while for stiff paste/mashy/porridge rice involves storage of paddy for 1 month followed by soaking for 5 days, parboiling at 80 °C and drying at 54.22 °C (Table 4.21).

Table 4.20: Predicted solutions of pasting properties for boiled *Ofada* rice

No	Soaking time,days	Parboiling temp. °C	Drying Temp° C	Storage, month	Trough	Breakdown	Setback	Desirability	
1	2.83	90.42	30.00	9.00	762	5.358	637.115	0.649	Selected
2	2.79	90.98	30.00	9.00	752.536	4.461	627.122	0.629	
3	2.91	89.35	30.00	8.96	782.291	7.516	655.152	0.628	
4	2.69	92.32	30.82	9.00	756.632	6.868	629.514	0.627	
5	2.52	104.88	70.00	9.00	693.246	35.995	677.479	0.626	
6	2.66	105.21	70.00	9.00	691.091	36.162	675.672	0.626	
7	2.38	104.14	70.00	9.00	704.594	37.205	689.195	0.625	
8	2.35	103.72	70.00	9.00	712.048	38.221	697.901	0.625	
9	2.55	106.95	69.49	9.00	671.799	31.732	639.308	0.623	
10	3.05	104.82	70.00	9.00	718.327	41.795	703.684	0.621	

Table 4.21: Predicted solutions of pasting properties of stiff mash

No	Soaking time,days	Parboiling temp. °C	Drying temp.° C	Storage, month	Breakdown	Setback	Desirability	
1	5.00	80.00	54.22	1.00	128.22	529.96	0.603	Selected
2	5.00	80.00	50.30	1.00	123.12	502.276	0.601	
3	5.00	80.22	50.38	1.00	122.73	500.371	0.601	
4	4.93	80.00	61.64	1.00	126.51	526.428	0.601	
5	4.92	80.00	61.89	1.00	125.95	524.397	0.6	
6	5.00	86.54	70.00	2.49	125.24	611.877	0.564	
7	5.00	92.31	69.95	4.04	126.15	725.065	0.519	
8	1.00	80.00	59.38	3.27	70.74	603.468	0.422	
9	1.02	80.00	59.31	3.29	70.95	606.957	0.422	
10	1.00	120.00	45.12	5.48	54.33	457.548	0.403	

4.6 Overall optimisation and validation of storage and processing conditions of *Ofada* rice

The result of the overall optimisation of quality properties (physical, chemical, cooking, and mineral) of *Ofada* rice investigated is presented (Table 4.22). The optimisation process was based on maximum length, maximum width, minimum breadth, maximum head rice yield, thousand grain weight in range, minimum broken grain, minimum chalkiness, low moisture content, maximum protein, minimum ether extract, maximum ash content, maximum carbohydrate, minimum fatty acids, maximum metebolizable energy, maximum amylose, minimum cooking time, maximum elongation, minimum solid loss, maximum water absorption ratio, minimum zinc level, minimum iron, minimum copper concentration, maximum levels of magnesium, potassium and calcium.

The best optimisation process for the storage of paddy and processing conditions to achieve these parameters as predicted include storage of rough rice for 8.63 months(8months and 19 days), soaking for 1 (one) day and19h:55min, parboiling at 113.04°C, and drying at 43.23°C to yield length of 5.92mm, breadth 2.06 mm, width 2.75 mm, 278.02 g thousand grain weight, 74.91 % head rice yield, 2.64 % brokenness, 0.08 % chalkiness, 71.05 % lightness, 5.68 % moisture, 9.28 % protein, 1.49 % ether extract, 0.65 % ash, 82.63 % carbohydrate, 0.17 crude fibre, 1.95 % fatty acid, 392.122 kcal/100g metabolizable energy, 22.10 % amylase, 38.68 min cooking time, 3.81 water uptake ratio, 3.73 % solid loss, 9.49mm elongation, 24.66 mg/kg Zn, 48.58 mg/kg Fe, 6.83 mg/kg Cu, 24.02 mg/kg K, and 0.34 mg/kg Ca.

The validation result of best processing condition predicted was presented (Table 4.22). Observation showed that most of the values were close to the predicted value except in few cases especially in mineral levels (Zn, Fe and K), cooking time and brokenness. The result of the validation demonstrated that the model is substantial in predicting the quality indices of *Ofada* rice which could be applied in arriving at a particular quality of rice in demand as dictated by the consumer’s market.

Table 4.22: Optimisation and validation of storage and processing conditions of *Ofada* rice

Parameters	Predicted	Validated
Length, mm	5.92	6.01
Width, mm	2.75	2.72
Breadth, mm	2.06	2.07
TGW, g	278.02	266.32
HRY, %	74.91	72.48
Brokenness, %	2.64	7.08
Chalkiness, %	-0.08	0.21
Lightness, L*	71.05	73.28
Moisture, %	5.68	8.59
Protein, %	9.28	10.01
Alter Ether extract, %	1.49	1.64
Ash, %	0.65	0.73
Carbohydrate, %	82.63	78.84
Crude fibre, %	0.17	0.19
Fatty acids, %	1.95	1.67
Metabolizable energy, kcal/kg	392.12	379.94
Amylose, %	22.1	22.86
Cooking time, min	38.68	32
Water uptake ratio	3.81	4.02
Solid loss, %	3.73	2.28
Elongation, mm	9.49	9.15
Zinc, mg/kg	24.66	33.27
Iron, mg/kg	48.58	77.36
Copper, mg/kg	6.83	8.06
Potassium, mg/kg	24.02	17.61
Calcium, %	0.34	0.36

4.7. Volatile and non volatile components of optimised Ofada rice

Ofada rice at optimum conditions for storage and processing were subjected to volatile and non volatile components analyses.The components in rough,parboiled and cooked rice grain were presented in Table 4.23. The rough rice contained more of alcohols, aldehydes and unsaturated fatty acids (6-octadecenoic acid, oleic acid, 11-octadecenoic acid, and 9-dodecenoic acid) while parboiled and cooked rice have more of aldehydes and ketones. A major focus has been on 2-acetyl-1-pyrroline (2-AP), the primary volatile compound in aromatic rice. However, this was not detected in rough, parboiled and cooked *Ofada* rice.

The presence of certain aldehydes, pentanal, indole and benzothiazole might have been responsible for the aroma in cooked and parboiled rice. According to Bryant *et al.*, (2011), benzothiazole is notable for slightly sweet aroma while pentanal is also found responsible for certain fruity flavour in rice while indole is known with sweet, floral and burnt flavour characteristics. Other groups of compounds such as ketones, esters and organic acids present may also have contributed to the aroma of cooked *Ofada* rice.

Lipid oxidation products and unsaturated fatty acids were identified in rough paddy which is known to have a negative impact on acceptability (Champagne, 2008). Unsaturated fatty acids like oleic acid and decenoic are antifungal. It is known that some fatty acids inhibit β-oxidation in mammals. These unsaturated fatty acids were not found in parboiled and cooked rice. The result revealed that processing parameters could eliminate unsaturated fatty acids in paddy during processing. The unsaturated fatty acids may become more prevalent with the length of storage time or due to poor post-harvest handling (Bryant *et al*., 2011).

The presence of acetic (organic acid), acetaldehydes (aldehydes) and glycoaldehydes contribute to aromatic nature of foods. The acetic acid and furfural can be generated as a result of hydrolysis of sugar or lignocelluloses materials of the rice bran (Cunha-Pereira *et al.*, 2010). Most of the volatiles identified in cooked *Ofada* rice were aldehydes (carbonicdihydrazide, 2-butyl-2-octenal, 2,4-pentadiene aldehyde, pentanal), ketones (2-dodecanone, 4-hydroxy-4methyl-2-pentanone), siloxane derivative (dimethyl silanediol) and volatile alcohols (1,2 ethane diol,, methyl alcohol). According to Lin *et al.*, (2010), rice contains aldehydes, ketones, esters, hydrocarbons, acids and heterocyclic volatile compounds. Aldol reactions of glycolaldehyde catalyzed by dipeptides can lead to pentose sugars in an enantioselective way, adding to the importance of glycolaldehyde in prebiotic chemistry (Altnoder *et al*., 2012).

As reported by Bergman *et al*., (2000) and Champagne (2008), more than 200 volatile compounds have been identified in rice. 2-AP, 2-acetyl-pyrrole,a-pyrrolidone, and pyridine, have been identified as enhancing the consumer acceptability of rice, while other compounds, such as lipid oxidation products, hexanal, acetic acid, and pentanoic acid, can have a negative effect on acceptability. Alcohols, phenols, and amines can give a pleasant aroma like 2-AP. Bryant *et al*., 2011 identified sixty four volatile compounds in aromatic and non aromatic rice cultivar. It was discovered that volatile compounds were more present in freshly harvested rice, with reduction or very few new compounds being identified only after storage. The major variation in the result could be the difference in the extraction method as solid phase microextraction (SPME) was used by Bryant *et al*., (2011).

Various methods have been reported in the literature for the synthesis of 2-acetyl-1-pyrroline (2AP). The first synthesis started from the hydrogenation process that reduced 2-acetyl-1-pyrrole into 2-(1-hydroxyethyl) pyrrolidine via rhodium on alumina catalyst and hydrogen. Because nitrogen heterocyclic compounds deactivate hydrogenation catalysts, a large quantity of expensive rhodium was necessary to complete the hydrogenation. A subsequent oxidation step via addition of silver carbonate on celite in benzene also produced the product 2AP (Ming-Chih, 2013). 2-Acetyl-1-pyrroline (2AP) which provides a rice-like and roasty aroma was reported as the primary odorant in various foods. However, due to the highly unstable nature of this compound, it is scarcely used commercially in flavor formulations. A novel and attractive method for stabilizing 2AP was successfully developed by formation of 2AP zinc iodide complex. Stability studies showed that 2AP zinc iodide complex was stable at ambient temperature (only 6% reduction after 3 months of storage at 25°C). Meanwhile, the ATHP-ZnI_2 complex was similarly stable and showed over 88% retention after 2 months of storage.

Table 4.23:Volatile and non volatile components in Ofada rice

Rough rice	Cooked rice	Parboiled rice
Methyl alcohol	1,2 ethane diol	Methyl alcohol
Acetaldehyde	Methyl alcohol	Acetaldehyde, hydroxyl
Glycolaldehyde	Acetic acid	Carbonic dihydrazines
6-octadecenoic acid	Carbonicdihydrazide	2-dodecanone
Oleic acid	2 benzothiazole	2 benzothiazole
11-octadecenoic acid	Dimethyl silanediol	1,2 ethane diol
9-dodecenoic acid	2-butyl-2-Octenal	dodecane
cyclopropanepentanoic acid	2,4-pentadiene aldehyde	hexadecane
2-dodecanone	benzene formaldehyde	2-pentyl - furan
1,2 ethane diol	4-hydroxy-4-methyl-2-pentanone	Indole
dodecane	2-dodecanone	undecane
2,6,10-trimethyl-pentadecane	Pentanal	
hexadecane	Naphthalene	
	Indole	

4.8. Chemical and functional qualities of ready-to-eat *Ofada* rice flakes

The result of chemical and functional qualities of ready-to-eat *Ofada* rice flakes produced from *Ofada* rice is presented (Table 4.24).

4.8.1 Moisture composition of ready-to-eat*Ofada* rice flakes

The minimum and maximum moisture content of the rice flakes were 3.10 and 6.89 respectively (Table 4.24). The standard deviation was 0.66 while the mean value obtained was 5.22 %. The least percentage moisture content was obtained from flake produced from *Ofada* paddy stored for 9 months and subjected to processing operations which involved 5 days of soaking, 80 °C parboiling, and 30°C drying temperature while the maximum moisture in the flake was obtained from the paddy stored for 1 month, soaked for 1 day, parboiled at 120 °C, and dried at 30 °C.

There were significant differences in the result of moisture contents obtained at $p < 0.05$.The R^2, Adjusted R^2, predicted R^2, and adequate precision were presented in Table 4.245and coefficient of the model depicting effect of processing condition and storage duration on *Ofada rice* in the production of rice flour in manufacturing of flakes is presented (Table 4.26). Positive coefficient of drying temperature showed that drying of paddy has a major influence on moisture content of flake. The movement of water out of the flake during drying and into the flake during food processing(water absorption) has implications on quality (Free, 2007). Flake thickness influences the rate of diffusion of water during drying. However, Machado *et al*, (1998) argued that range of thickness did not correlate with water absorption.

Oeding (1996) has profound that higher steam temperature and moisture during steaming resulted in increased water absorption, and also suggested that this was related to changes in pasting behaviour. The report justified the result of this experiment with rice parboiled at highest temperature measuring highest percentage of moisture while this decreased with reduction in parboiled temperature. Mid parboiling temperature (100 °C) and soaking time (3 day) are adequate to produce rice flakes of low moisture content that can be stable as required in the standard quality of flakes.

The extreme low and high drying temperature and storage duration are recommended to give rice flakes of least moisture composition. High drying temperature causes thermal damage during dehydration

Table 4.24: Chemical and functional composition of *Ofada* rice flakes

Number	Soaking Time,day	Parboiling temp.°C	Drying Temp.°C	Storage Duration	Moisture %	Protein %	Ether extract %	Ash %	Carbohydrate %	Phytate %	Water absorption ratio	Metabolisable energy,kcal/100g
1	5	120	70	1	5.9	8.5	0.89	2.93	81.78	0.8	2.37	368.46
2	1	80	70	1	5.6	8.81	1.49	2.4	81.7	1.51	3.43	374.81
3	1	80	30	5	6.25	9.73	0.3	1.28	82.44	1.47	4.34	382.63
4	5	80	30	1	5.6	8.77	0.49	1.57	83.57	0.69	2.65	373.03
5	5	80	30	9	5.65	12.84	0.49	1.59	79.43	1.15	4.29	383.53
6	3	80	50	5	5.15	10.26	0.52	0.95	83.12	1.46	4.77	389.33
7	5	120	30	5	5.4	9.64	0.4	0.2	84.36	0.39	4.51	391.11
8	1	80	70	1	5.69	8.9	0.97	2.43	82.01	1.36	3.41	371.67
9	5	120	70	9	5.75	12.21	0.51	1.68	79.85	0.51	4.41	383.09
10	3	120	50	5	5.85	10.5	0.37	1.13	82.15	0.62	4.17	384.95
11	3	120	30	9	3.7	13.1	0.66	1.6	80.94	0.92	4.55	392.28
12	5	100	50	5	5.25	10.19	0.31	1.03	83.22	0.64	4.69	387.72
13	1	120	70	5	5.1	9.76	0.24	1.03	83.87	1.01	4.88	388.19
14	3	100	50	9	3.73	13.01	0.76	1.72	80.76	1.09	4.74	392.02
15	1	120	50	9	5.6	12.81	0.32	1.52	79.75	1.14	4.32	383.37
16	5	120	70	1	5.24	8.62	0.86	2.94	82.34	0.72	2.38	370.89
17	1	100	50	5	5.3	9.96	0.46	1.12	83.16	1.36	4.59	387.84
18	3	100	50	5	4.05	6.99	0.46	2.63	86.87	0.89	2.95	378.99
19	5	80	30	1	5.01	8.81	0.56	1.65	83.97	0.71	2.67	375.42
20	1	120	30	1	6.89	9.36	0.63	1.42	85.79	1.42	3.22	385.49
21	1	100	30	9	3.33	12.76	0.44	1.74	81.73	1.53	4.52	392.42
22	5	80	70	5	6.85	9.94	0.43	1.01	81.77	1.42	4.66	381.73
23	1	80	70	9	3.8	12.93	0.52	2.05	80.7	1.67	4.21	389.46
24	5	80	30	9	3.1	12.61	0.38	1.65	82.26	1.22	3.92	393.55
25	1	120	30	1	6.82	9.28	0.67	1.41	81.82	1.25	3.24	369.66

Table 4.25: ANOVA of regression of chemical and functional qualities of *Ofada* rice flakes

Parameters	p-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Moisture, %	0.0207	0.84	0.6161	-0.187	7.088
Protein, %	0.0019	0.9084	0.7802	-0.082	7.58
Ether extract, %	0.0029	0.8991	0.7579	0.3474	9.795
Ash, %	0.0267	0.8297	0.5914	-1.6124	7.966
Carbohydrate, %	0.146	0.7318	0.3562	-0.9228	5.317
Phytate, %	<0.0001	0.9662	0.919	0.6943	16.673
Water absorption ratio	0.0229	0.8361	0.6066	-1.5452	5.835
Metabolisable energy, kcal/100g	0.0627	0.7882	0.4917	-0.8638	5.013

Table 4.26: Coefficient of the quadratic model for the effect of storage and processing parameters on *Ofada* rice quality in production of ready to eat flakes

	Moisture (%)	Protein (%)	Ether extract (%)	Ash (%)	CHO (%)	Phytate, %	Water absorbtion	M.E kcal/100g
Intercept	36.41	23.04	-0.76	-4.27	38.55	2.77	3.56	296.21
S	-2.31	-0.65	-0.02	0.42	2.9	-0.12	-0.45	3.72
P	-0.66	-0.37	0.03	0.16	1.01	-0.03	-0.03	1.44
D	0.21	0.19	0.03	-0.06	-0.39	0.01	0.04	-0.21
T	-0.27	-0.09	-0.24	-0.34	0.79	0.18	0.48	5.86
S^2	0.28	0.12	-0.03	-0.12	-0.3	$6.30X10^{-3}$	0.08	-0.27
P^2	$3.33x10^{-3}$	$2.02x10^{-3}$	$-1.44x10^{-4}$	$-9.17x10^{-4}$	$-4.89x10^{-3}$	$2.17x10^{-4}$	$2.19x10^{-4}$	$-5.92x10^{-3}$
D2	$-2.30x10^{-3}$	$-1.45X10^{-3}$	$-1.55X10^{-5}$	$3.42X10^{-4}$	$3.68X10^{-3}$	$2.97X10^{-5}$	$-3.32X10^{-6}$	$5.65X10^{-3}$
T2	-0.03	0.07	0.02	0.06	-0.11	$3.38X10^{-3}$	-0.05	-0.32
SP	$-2.63X10^{-3}$	$-1.63X10^{-3}$	$1.87X10^{-3}$	$2.62X10^{-3}$	$-3.99X10^{-3}$	$-2.11X10^{-3}$	$-1.75X10^{-3}$	$-1.44X10^{-3}$
SP	6.01	$2.12X10^{-3}$	$-1.55X10^{-4}$	$1.19X10^{-3}$	-0.01	$3.40X10^{-3}$	$7.94X10^{-4}$	-0.04
ST	0.04	$-6.07X10^{-3}$	$8.27X10^{-3}$	$-8.16X10^{-3}$	$-7.57X10^{-3}$	$-1.30X10^{-3}$	0.02	$5.19X10^{-3}$
PD	$-3.18X10^{-4}$	$-5.50X10^{-4}$	$-1.47X10^{-4}$	$4.73X10^{-4}$	$2.29X10^{-4}$	$-2.03X10^{-4}$	$-3.98X10^{-4}$	$-3.26X10^{-3}$
PT	$1.98X10^{-3}$	$-5.35X10^{-4}$	$2.42X10^{-4}$	$-1.50X10^{-3}$	$-3.28X10^{-3}$	$-1.43X10^{-3}$	$1.95X10^{-3}$	-0.01
DT	$1.81X10^{-3}$	$-9.5X10^{-4}$	$-1.06X10^{-3}$	$-2.08X10^{-3}$	$5.53X10^{-3}$	$-9.09X10^{-4}$	$-3.65X10^{-4}$	$3.95X10^{-3}$

S-soaking time; P-parboiling temp.; D-drying temp.; T- storage duration temperature this is usually responsible for the low water activity and flake instability (Sapers *et al*., 1974).

4.8.2. Protein composition of ready-to-eat *Ofada* rice flakes

The results of the protein content of rice flakes ranged between 6.99 to 13.10 % (Table 4.24). Some of the values obtained in this study were comparable to protein content in wheat (USDA 2010). There exist significant differences in the result for protein at $p < 0.05$ and values of R^2, Adjusted R^2, predicted R^2, and adequate precision were presented in Table 4.24. The closeness of R^2 and Adjusted R^2 to 1 and extent of greatness of adequate precision above 4 were indicators of the degree of fitness of the model. The coefficient of the model is presented (Table 4.26).

Maximum protein content in rice flake was obtained from paddy stored for 9 months, and subjected to 3 days soaking, 100°C parboiling temperature, and 50°C drying temperature. The response surface plots showing the effect of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temperature and drying temperature, parboiling and storage duration, drying temperature and storage duration on protein content of *Ofada* rice flakes were presented (Figs. 4.67 - 4.72).

As revealed in response surface graph (Fig.4.67), soaking and parboiling produce skewed curve with mid experimental parboiling temperature and soaking time producing the least protein. Ready to eat *Ofada* rice flakes produced from paddy stored for longer duration relatively shown improvement in the protein content (Figs.4.69, 4.71 and 4.72) while drying temperature plots were concave downward showing that the mid experimental drying temperature favoured high protein (Figs.4.68, 4.70 and 4.72).

The protein composition recorded in this experiment was higher than the result recorded by most authors (Nazni and Bhuvaneswari, 2011), however, when the nutritional protein composition was compared with the popular ‘Kelloggs’ products, it was found that *ofada* rice flakes protein were higher

4.8.3. Fat content of ready-to-eat *Ofada* rice flakes

Fat content results were significant at $p < 0.05$ and ranged from 0.24 to 1.49 % with mean value of 0.57 %. Generally, the ether extracts were low (<1.5 %) with the maximum extract recorded from the flake produced from paddy stored for 1 month and treated under 1 day soaking, 80°C parboiling and 70°C drying temperatures respectively while the minimum value was from rice stored for 5 months, and processed by soaking for 1 day, parboiling at 120°C and drying temperature at 70°C. The coefficient of the model is presented (Table 4.26).

The response surface plots showing the effect of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temperature and drying temperature, parboiling temperature and storage duration, drying temperature and storage duration on fat content of *Ofada* rice flakes were presented (Figs. 4.217 -4.222). The effect of the soaking time on the fat of rice flakes showed tendency of obtaining least fat at the minimumand maximum soaking time as prescribed in the experiment. There was a slow steady increase in fat content with increase in drying temperature.

The result obtained from this experiment is comparable to the general fat content recorded for most commercial rice flakes (Fatsecret, 2013). High fat content can easily cause rancidity of the package foods, however, maximum of 3 % fat has been found in most commercial rice flakes. Gupta *et al.*, (2012), recorded fat content range of 0.76 – 5.91 % in the production of rice flakes mix using dehydrated herbs.

4.8.4.Ash contents of ready-to-eat *Ofada* rice flakes

The ash content is the total mineral composition of rice flakes and it ranged from 0.20 to 2.94 %. The model F-value of 3.48 implied the model was significant. Maximum ash content was from rice flake produced from the paddy stored for 1 month followed by soaking of the rough rice for 5 days, parboiling at 120 °C, and drying at 70 °C while minimum value was obtained from rice stored for 5 months, soaked for 5 months, parboiled at 120 °C and dried at 30 °C. It was observed from the factors that the effect of storage duration and drying temperature could have been the responsible for the variation.

The lack of fit value was significant which is not good for the fitness of the model for predicting ash quality of rice flakes. However, values of R^2, Adjusted R^2, predicted R^2, and adequate precision were presented and coefficient of the model were presented in Table 4.25 and 4.26 respectively. Soaking time (S) and parboiling temperature (P) in the treatment of paddy rice for flake production have effect on the ash content of the flakes as shown by the coefficient of the model (Table 4.26).

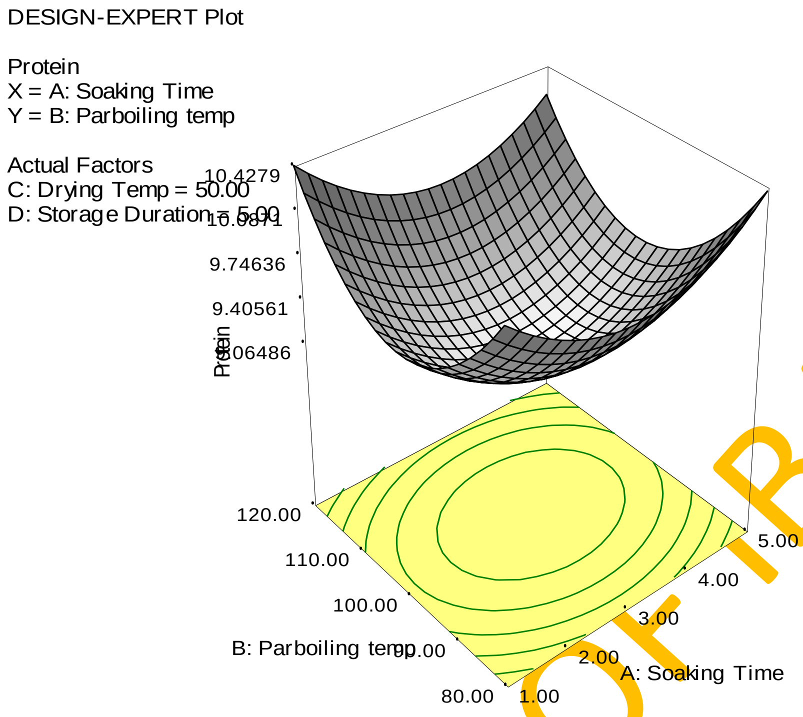

Fig.4.67: Effect of soaking time and parboiling temperatureon protein of rice flakes

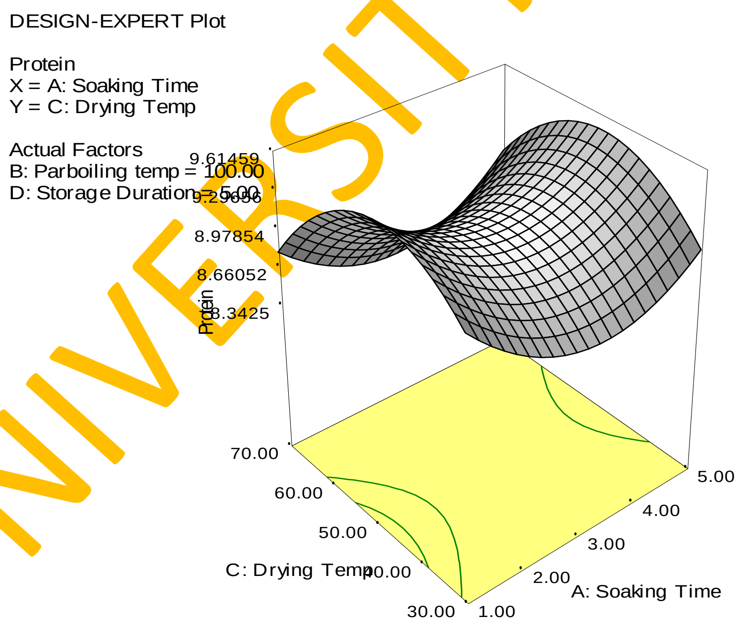

Fig.4.68: Effect of soaking time and drying temperature on protein of rice flake

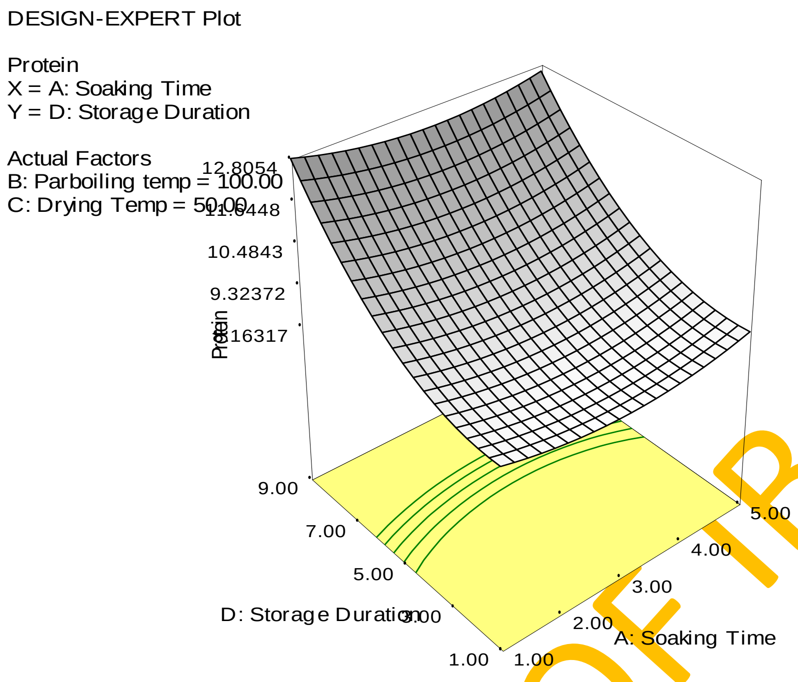

Fig.4.69: Effect of soaking time and storage duration on protein in rice flakes

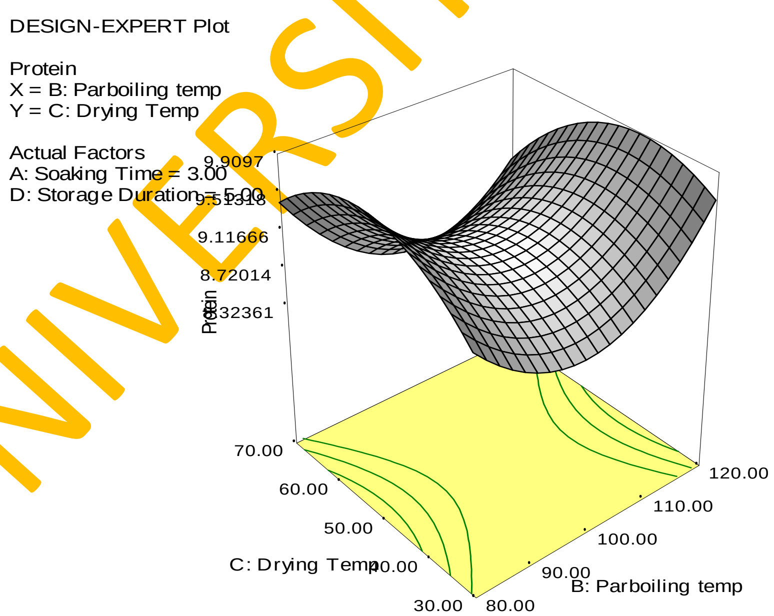

Fig.4.70: Effect of parboiling and drying temperature on protein in rice flake

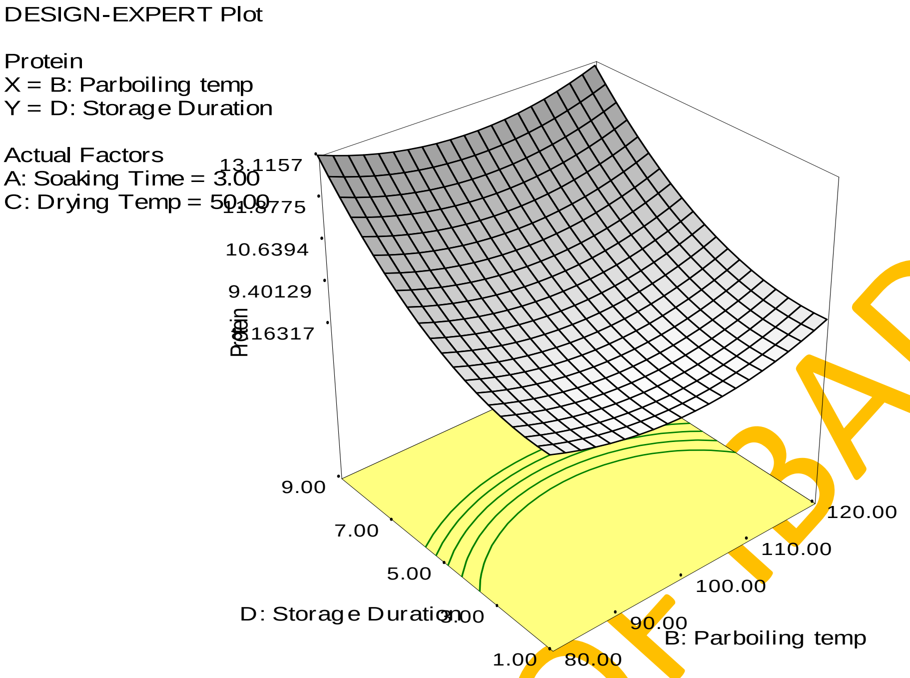

Fig.4.71: Effect of parboiling temperature and storage duration on protein in rice flakes

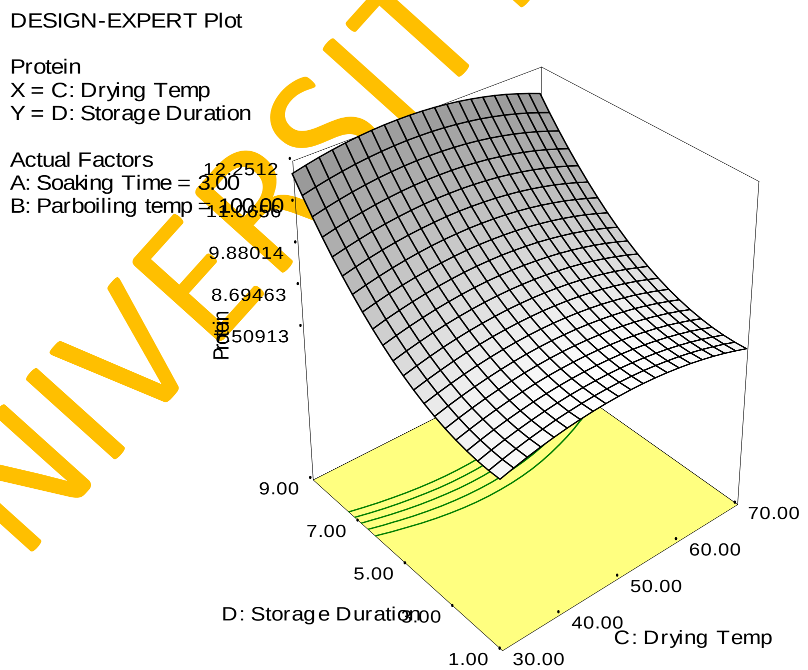

Fig.4.72: Effect of drying temperature and storage duration on protein in rice flakes

4.8.5. Carbohydrate contents of ready-to-eat *Ofada* rice flakes

There was no significant difference in the data obtained for carbohydrate and the result ranged from 79.43 – 86.87 % (Table 4.24). The "Lack of Fit test" is not significant with the F-value of 0.66. The values of R^2, Adjusted R^2, predicted R^2, and adequate precision of the model were presented in Table 4.25. Carbohydrates are the macronutrient that human need in the largest amounts. According to the Dietary Reference Intakes published by the USDA, 45% - 65% of calories should come from carbohydrate. It is the body's main source of fuel and energy. Carbohydrates are needed for the central nervous system, the kidneys, the brain, the muscles (including the heart) to function properly (Fatsecret, 2013).

It was documented by Fatsecret (2013) that when carbohydrate consumption levels are at or above 75% of total energy there could be significant adverse effects on nutritional status by the exclusion of adequate quantities of protein, fat and other essential nutrients. In arriving at its recommendation of a minimum of 55% of total energy from carbohydrate, the consultation realised that a significant percentage of total energy needs to be provided by protein and fat, but that their contribution to total energy intakes will vary from one country to another on the basis of food consumption patterns and food availability.

4.8.6. Water absorption of ready-to-eat *Ofada* rice flakes

Water absorption is one of the major factors in determining the quality of flakes. The results obtained ranged from 2.37 to 4.88. The result showed that there were significant differences in the water absorption ratio values of the rice flakes ($p<0.05$). Observation of the data revealed that the rate of water absorption majorly varied with the storage duration of paddy before processing.

However, the highest water absorption ratio was obtained in rice flakes processed from rice subjected to 1 day soaking, 120 °C parboiling temperature, 70 °C drying after storage for 5 months duration. However, values of R^2, Adjusted R^2, predicted R^2, and adequate precision were presented (Table 4.25). The coefficient of the model showed a positive influence of drying temperature (D) and storage duration (T) on raw material processing (paddy) in manufacturing of flakes (Table 4.26). The effect of soaking time and parboiling temperature, soaking time and drying temperature, soaking and storage duration, parboiling temperature and drying temperature, parboiling and storage duration, drying temperature and storage duration on water absorption of *Ofada* rice flakes were presented (Fids. 4.73-4.78).

4.8.7. Phytate composition of ready-to-eat *Ofada*flakes

Rice contains some important anti-nutritional factors, most which are concentrated in the bran. All anti nutritional factors in rice except phytate are proteins and denatured by heat. The phytate levels from the experiment ranged from 0.39 to 1.67 %. Variation in respect of phytate content was found to be significant ($p < 0.05$). The highest amount of phytate was recorded in the flake produced from rice stored for 9 months, processed by soaking for 1 day, 80 °C parboiling temperature, and 70 °C drying temperature while the least value of phytate was at 5 days soaking, 120 °C parboiling, 30°C drying and 5 months storage duration of paddy. R^2, Adjusted R^2, predicted R^2, and adequate precision values were presented (Table 4.25). The low value of standard deviation (0.01) increased the degree of fitness of the model and the coefficient of the model is presented. However, increase in drying temperature and storage duration improved phytate of rice flakes which showed that reduction in drying temperature and short storage duration may prevent accumulation of phytate content in flakes (Table 4.23).

According to Noreen *et al.*, (2009), soaking and boiling processes caused significant decrease in phytic in rice. This report may be related to the reason why soaking at longest day and highest degree of parboiling temperature resulted to the least value of phytate while the opposite of the processing conditions in terms of soaking and parboiling gave the highest phytate value in the rice flake. Humans have limited ability to absorb and hydrolyse phytate (Pawar and Ingle, 1988). Binding of minerals with phytic acid decrease bio availability of calcium, iron, phosphorus, zinc and other trace elements to human and other monogastric

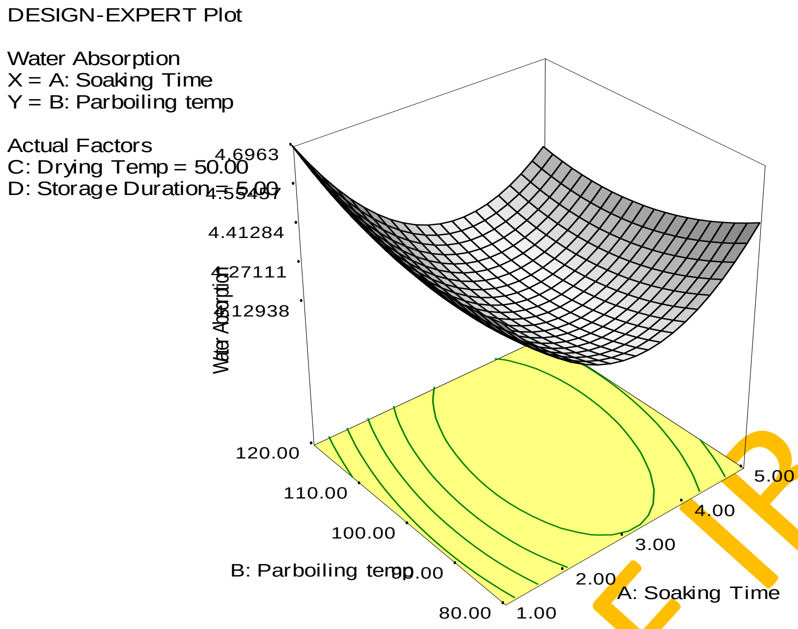

Fig.4.73: Effect of soaking time and parboiling temperature on water absorption ratio of flakes

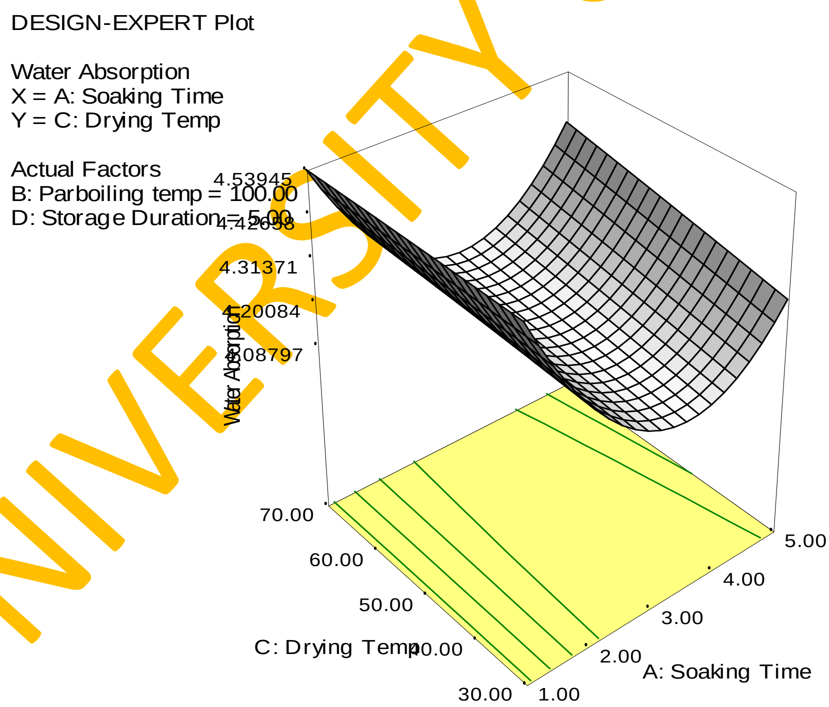

Fig.4.74: Effect of soaking time and drying temperature on water absorption ratio of flakes

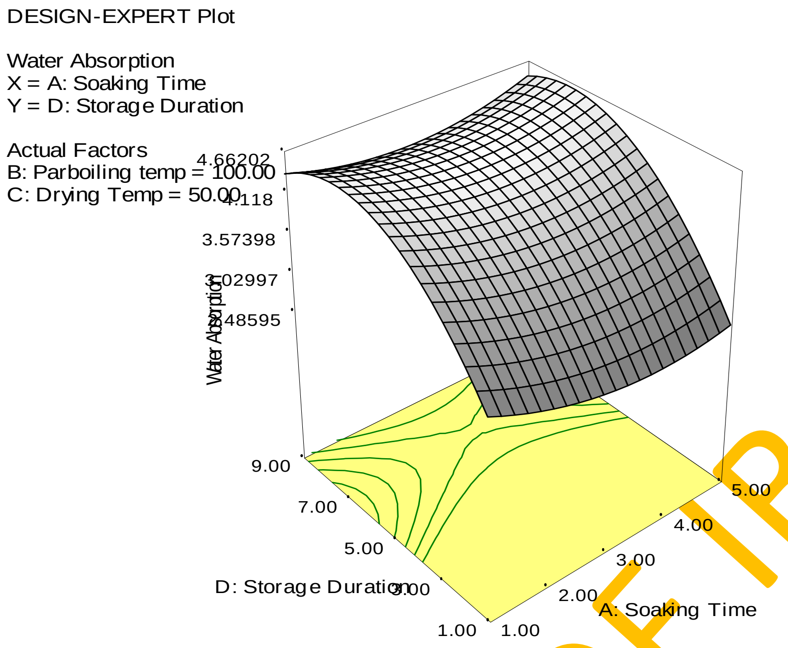

Fig.4.75: Effect of soaking time and storage duration on water absorption ratio of flakes

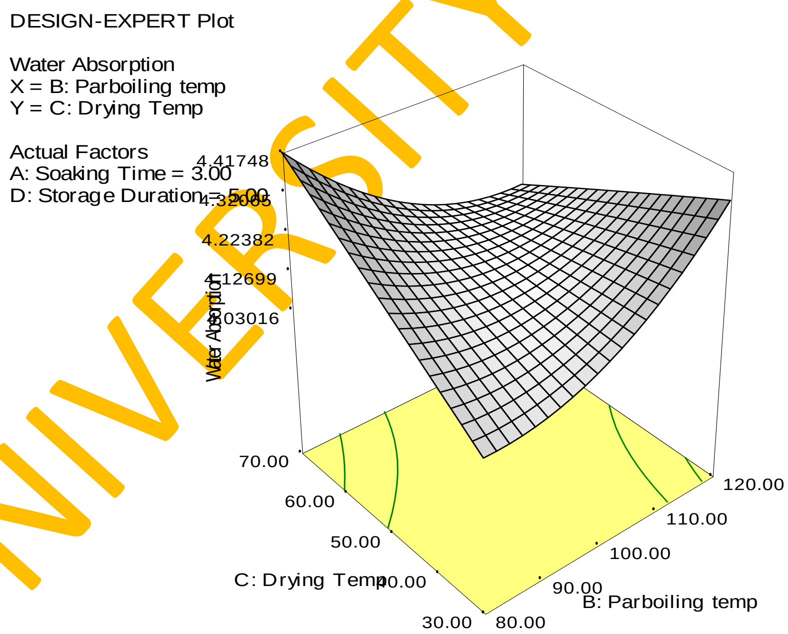

Fig.4.76: Effect of parboiling and drying temperature on water absorption ratio of flakes

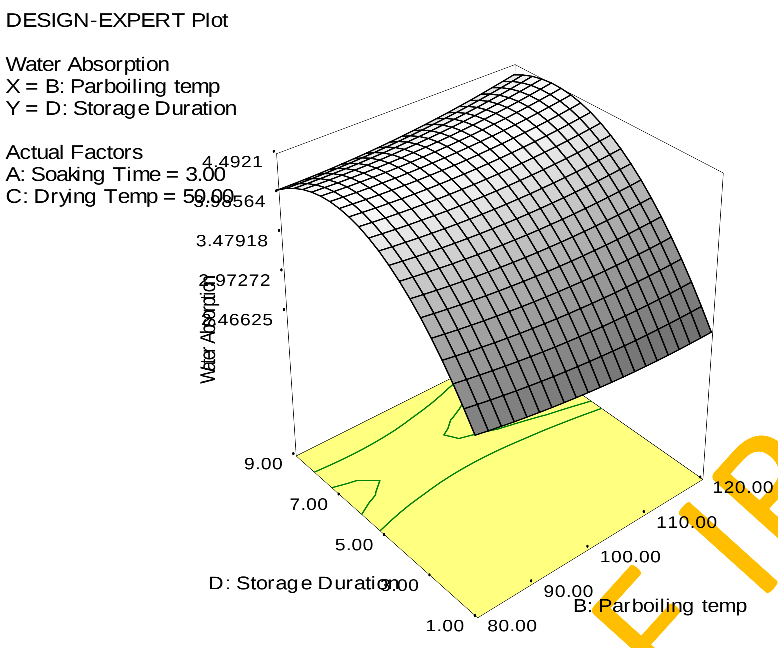

Fig.4.77: Effect of parboiling temperature and storage duration on water absorption ratio offlakes

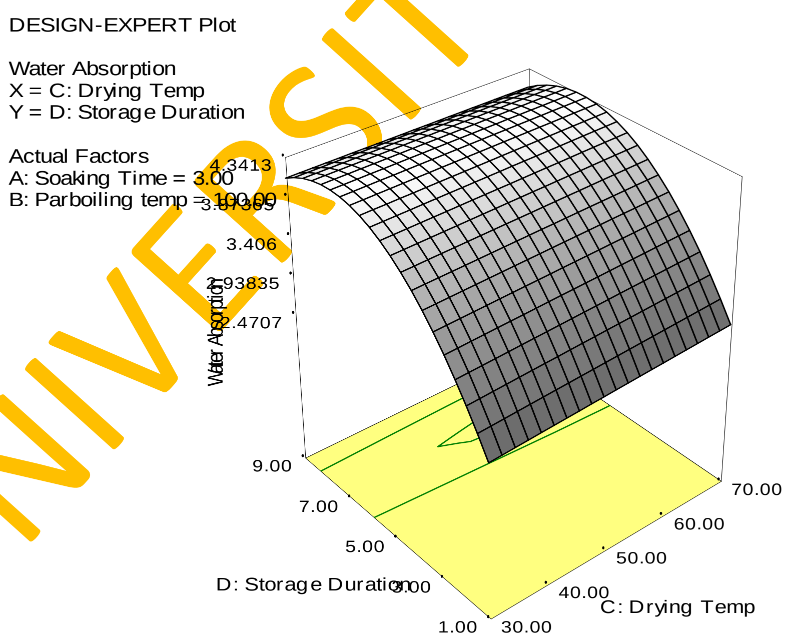

Fig.4.78: Effect of drying and storage on water absorption ratio of flakes

animals. This may lead to severe nutritional and consequently health problems in the consuming population (Thompson (1987).

4.8.8. Metabolization energy of ready-to-eat *Ofada* rice flakes

The metabolizable energy in the flakes was between 368.46 and 393.55 kcal/100g. There exist no significant difference ($P > 0.05$) in the metabolizable energy obtained from the rice flakes as affected by the processing condition and storage duration of paddy before processing. The "Lack of Fit" for the model is non significant with the F-value of 0.71. The R^2, Adjusted R^2 and standard deviation were 0.7882, 0.4917 and 5.64 respectively (Table 4.25). The effect of soaking were relatively stable while increase in parboiling temperature brought about increase in metabolisable energy.

4.9. Optimisation and validation of chemical quality of ready-to-eat *Ofada* flakes

The optimisation of the ready to eat *Ofada* rice flake was based on quality indices and level of desirability expected from high profile ready to eat flakes. These indices include maximum protein for good nutrition, minimum ether extract to prevent rancidity, minimum moisture to increase its shelf life and to prevent microbial activities, maximum ash represents total mineral composition which is also vital in nutrition because of their various functions, carbohydrate was not specified since the product have high carbohydrate value, minimum phytate (anti-nutritional factor usually found in rice), maximum metabolizable energy and maximum water absorption.

There were ten solutions suggested with desirability range of 0.745 to 0.783 with the first predicted solution having the highest desirability (Table.4.27). This involved storage of paddy for 9 months, soaking for 4 days and 17h, parboiling at 106°C and drying at 30°C before milling to flour of desired particle size for the production of ready to eat flakes to yield 3.10% moisture, 12.16 % protein, 0.67 %

ether extract, 1.62 % ash, 393.19 kcal/100g, 0.67 % phytate, and 4.40 water absorption ratio. However, the first three solutions as presented (Table 4.27) have similar desirability with high closeness of processing conditions and the same storage duration of paddy. Observations of the yields were also closely related.

The result of the validation of the best predicted solution showed yields of 4.08 % moisture, 11.93 % protein, 0.86 % ether extract, 1.92 % ash, 81.21 %, 390.604kcal/kg, 4.57 water absorption and 0.32 % phytate. However, the results of the validation are closer to the result predicted by the response surface.

Table 4.27:Optimization of chemical and functional properties of *Ofada* rice flakes

S/N	Soaking Time,day	Parboiling temp.	Drying Temp.	Storage Duration	Moisture %	Protein %	Ether Extract,%	Ash %	Phytate %	Water absorption ratio	Metabolisable energy,kcal/100g	Desirebility	
1	4.70	106.16	30.00	9.00	3.1	12.164	0.67	1.621	0.665	4.4035	393.192	0.7832	Selected
2	4.75	105.32	30.00	8.99	3.099	12.148	0.663	1.619	0.67	4.40266	393.191	0.7831	
3	4.62	107.24	30.07	9.00	3.099	12.178	0.678	1.63	0.664	4.40116	393.166	0.7829	
4	4.79	103.94	30.13	9.00	3.102	12.144	0.654	1.63	0.685	4.39364	393.112	0.7824	
5	4.90	99.66	30.01	9.00	3.099	12.123	0.623	1.651	0.743	4.36695	392.962	0.7787	
6	1.94	114.80	70.00	9.00	3.1	11.818	0.466	2.183	0.881	4.21874	388.686	0.7774	
7	2.06	114.92	70.00	9.00	3.1	11.793	0.479	2.207	0.866	4.20355	388.584	0.7773	
8	1.92	114.76	70.00	9.00	3.099	11.816	0.463	2.178	0.883	4.22206	388.71	0.7773	
9	1.91	114.54	70.00	8.93	3.099	11.745	0.458	2.178	0.887	4.23492	388.817	0.7773	
10	3.64	113.71	30.00	8.95	3.1	12.269	0.698	2.178	0.786	4.37523	392.861	0.7773	

4.10. Sensory evaluation of ready to eat *Ofada* rice flakes

The first, sixth and tenth predicted solutions were chosen for sensory evaluation based on variation of the levels of processing conditions. The ready to eat *Ofada* rice flakes manufactured were subjected to sensory analysis (colour, crispiness, taste, aroma, and overall acceptability) based on a nine point hedonic scale, where 1 is dislike extremely and 9 is like extremely. The result of the sensory analysis is presented (Table 4.28).

There exist no significant differences ($p > 0.05$) in crispiness, taste, and aroma, however, significant difference was shown in colour attribute with flakes produced from tenth predicted solution been rated better than others. For the overall acceptability, the first solution was most accepted.

4.11. Moisture adsorption of *Ofada* rice flakes

The moisture sorption characteristic of Ofada rice flakes is presented in Fig. 4.79. Observation from the Figure presented revealed type II isotherm (sigmoidal). Equilibrium moisture content increased at the same relative humidity as temperature decreased. This is an indication that samples absorbed more moisture at lower temperature than when the temperature is high. Several works of other authors reported similar finding (Vega-Gálvez *et al*.,, 2008; Ajisegiri *et al*., 2007). According to Taoukis *et al*., (1988), lose of crispiness and texturally acceptability may be as a result of increase in water activity from 0.35 to 0.5.

The general trend of sorption isotherm as a function of temperature was shown in Fig.4.79. The percentage relative humidity (RH %) was converted to water activity (a_w). Over the range of water activity at lower temperature there was an increase in the equilibrium moisture content as also reported by Vega-Galvez *et al*., (2008). The equilibrium moisture content increased at the same water activity as temperature decreased. This may be due to the fact that food materials absorb more moisture at low temperature than when the temperature is high and water molecules have lower kinetic energy at low temperature which is not enough to overcome the corresponding sorption energy (Vega-Galvez *et al.*, (2008). Mould growth was observed on all the samples kept at 90 % relative humidity of 25 ºC and 35 ºC and presumes not to have significant effect on the final moisture content of the samples (Alam and Singh, 2011).

The parameter values at 25, 35 and 45 ºC of all the models used (Brunauer, Emmett and Teller (BET), Guggenheim Anderson de- Boer (GAB), Oswin, and Halsey) for the adsorptions were shown in Table 4.28. The high regression coefficient (R^2), percentage deviation, % E lower than 12 % and root mean square error (RMSE) close to zero for the isotherms and temperatures as obtained in the experiment have shown that all the models were fit. GAB recorded highest regression coefficient (0.985-0.981), lowest root mean square error value (RMSE) (0.18 and 0.09 at 25 ºC and 35 ºC respectively). However, based on the average values of the statistical parameters, GAB has the best fitness for the three temperatures studied. The GAB and BET models were used to estimate the monolayer moisture content.

The monolayer moisture content is the moisture of a material when its entire surface is covered with a unimolecular moisture layer (Alakali *et al.*, 2009). It is referred to moisture content of maximum stability. As presented in Table 4.29, the monolayer moisture decreased with increase in temperature for samples tested which may be due to reduction in the number of active site for water binding because of the physical and chemical changes in the product induced by temperature (Alakali *et al.*, 2009). These observations imply that the optimum moisture for shelf stability of *Ofada* flake will be determined in relation to anticipated temperature of storage.

Table 4.28: Sensory evaluation of *Ofada* rice flakes

Ofada rice flakes	Colour	Taste	Aroma	Crispiness	Overall Acceptability
First solution	6.7a	7.1a	6.9a	6a	7.30a
Sixth solution	6.3a	7.5a	7.2a	6.3a	6.4ab
Tenth solution	7.8b	7.20a	6.80a	6.2a	6.6a

Note: Compared values with the same alphabet are not significantly different while those which differalphabetically showed significant differences at $p<0.05$.

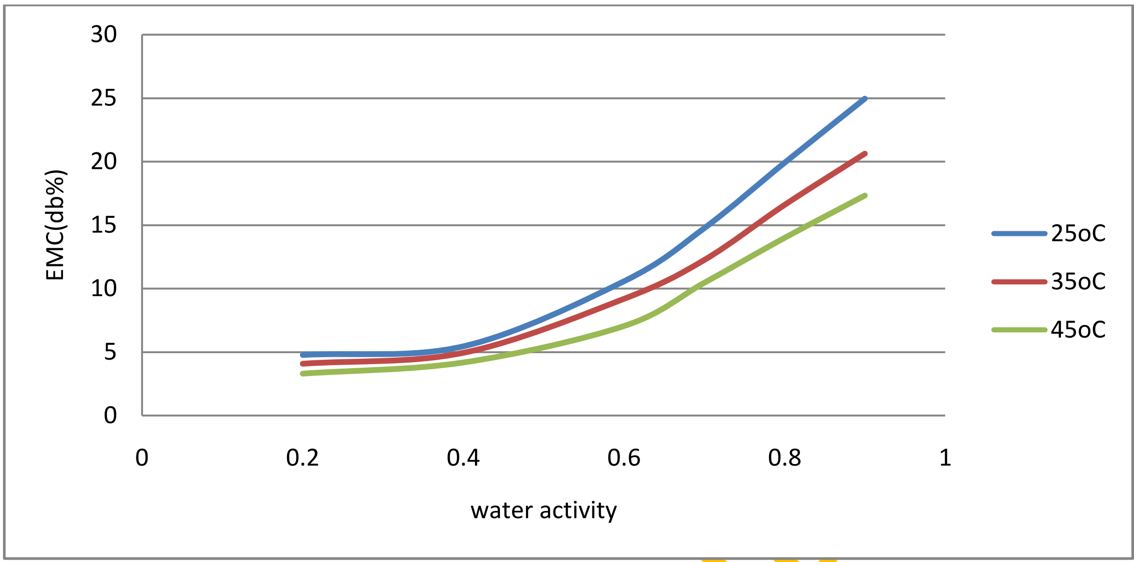

Figure 4.79: Experimental adsorption isotherms of *Ofada*flakes at three working temperatures

Table 4.29: Equation and statistics value of four different equation

Sorption Isotherm at 25oC — Equation coefficients

Model	Equation	R2	A	B	C	E%	RMSE	Cal. F. value	Prob.F. value
GAB	A*B*C*aw/((1-C*aw)*(1+(B-1)*C*aw))	0.982	9.467	2.104	0.769	0.073	0.18	241.69	9.28
BET	A*C*aw/((1-aw)*(1+(C-1)*aw))	0.745	2.995		3.99E+07	1.273	3.067	31.884	6.94
Oswin	A*(aw/(1-aw))**C	0.963		9.132	0.479	-0.076	0.183	235.139	4.53
Halsey	(-A/Ln(aw))**B	0.946		34.637	0.565	-0.12	0.29	157.809	6.94

Sorption Isotherm at 35oC — Equation coefficients

Model	Equation	R2	A	B	C	E%	RMSE	Cal. F. value	Prob.F. value
GAB	A*B*C*aw/((1-C*aw)*(1+(B-1)*C*aw))	0.985	7.064	2.925	0.784	0.044	0.09	303.32	9.28
BET	A*C*aw/((1-aw)*(1+(C-1)*aw))	0.713	2.496		1.10E+08	1.37	2.37	29.889	6.94
Oswin	A*(aw/(1-aw))**C	0.968		7.823	0.479	-0.067	0.137	280.948	4.53
Halsey	(-A/Ln(aw))**B	0.95		29.634	0.547	-0.11	0.223	179.504	6.94

Sorption Isotherm at 45oC

Model	Equation	R2	A	B	C	E%	RMSE	Cal. F. value	Prob.F. value
GAB	A*B*C*aw/((1-C*aw)*(1+(B-1)*C*aw))	0.981	6.251	2.4	0.777	0.061	0.1033	228.514	9.28
BET	A*C*aw/((1-aw)*(1+(C-1)*aw))	0.732	2.091		2.26E+07	1.307	2.207	30.809	6.94
Oswin	A*(aw/(1-aw))**C	0.962		6.435	0.473	-0.075	0.127	230.796	6.94
Halsey	(-A/Ln(aw))**B	0.944		19.306	0.559	-0.119	0.2	337.197	6.94

A- Monolayer moisture content; B and C are constants

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

Response surface methodology was used successfully in the optimisation and modelling effect of storage duration and processing parameters on *Ofada* rice and flakes quality.The results of rice and flakes analysis showed significant differences ($p<0.05$) as affected by storage duration and processing parameters except in thousand grain weight, colour value, ash content, elongation, magnesium, breakdown viscosity of rice while carbohydrate and metabolisable energy of flakes were not significant. The multiple correlation coefficients (R^2) of rice for the models ranged between 0.3562-0.948 for physical qualities, 0.5149-0.9573 for chemical qualities, 0.609-0.9687 for cooking properties and 0.3562-0.919 for chemical qualities of flakes.

The sensory assessment has revealed that local rice such as *Ofada* rice could be used for the production of ready-to-eat flakes of good quality.Optimum processing of *Ofada* paddy for ready-to-eat flakes production include storage of paddy for 9 (nine) months, soaking for 4 (four) days and 17 h, parboiling at 106 °C and drying at 30 °C before milling to flour.

Optimum conditions for storage and processing of Ofada paddy for various end uses include;

- Best physical quality requires storage of paddy for storage 1 (one) month, soaking of paddy for 1 (one) day, parboiling at 119.92°C, and drying at 30°C.
- Best chemical quality requires storage of paddy 9 (nine) months, soaking for 1 day and 19h, parboiling at 120°C and drying at 30°C.
- Best indices for cooking properties could be attained by storage of paddy for 9 (nine) months, soaking of paddy for 5 (five) days, parboiling at 80°C and drying at 55°C.

- Best mineral requirement involved storage of paddy for 9 (nine) months, soaking for 1 (one) day 9h, parboiling at 115°C and drying at 58°C.
- Pasting requirement for boiled rice is storage of paddy for 9 months, soaking for 2 (two) days and 19h, parboiling at 90.42^{0}C, and drying at 30^{0}C.
- Pasting requirement for mashed rice include storage of paddy for 1 (one month),
  soaking 5 (five) days, parboiling at 80°C, and drying at 54°C.
- Overall optimisation of processing and storage duration for optimum physical, chemical, mineral, and cooking properties of *Ofada* rice include storage of paddy for 8 (eight) months and 19 (nineteen) days, soaking for 1 day and 19 h: 55 min, parboiling at 113.4^{0}C and drying at 43.23^{0}C.

Moisture adsorption of *Ofada* flakes produced J shaped curve which can be classified as type II. The equilibrium moisture content of the flakes increased with decrease in temperature at a constant water activity.

Out of the models tested, Brunauer, Emmett and Teller (BET), Guggenheim Anderson de- Boer (GAB), Oswin, and Halsey for the adsorptions, GAB is rated best for the fitness and with calculated monolayer moisture range between 6.251-9.467 and 2.091-2.995 for BET which decreased with increase in temperature.

Response surface methodology was applied for the optimisation and modelling of processing parameters (soaking time, parboiling temperature, and drying temperature) and storage duration of paddy rice for quality and production of *Ofada* ready-to-eat flake. The study revealed appropriate best practices for *Ofada* rice processing operations for the purpose of upgrading its physical, chemical, functional, and cooking properties for various end uses, production of flakes and determination of its moisture adsorption in storage.

5.2. Recommendation

The following recommendations were suggested for further studies:

I. Optimisation and modelling of quality of other variety of Nigerian local rice as affected by storage duration and processing condition should also be investigated.

II. Sensory quality of ready-to-eat rice flake produce from non parboiled *Ofada* rice is also a green area of pending research.

III. Processing operations for the manufacture of ready-to-eat*Ofada* rice flake should also be studied for the purpose of optimisation.

5.3. Contribution to knowledge

- The results of this study made available relevant technical data on optimum storage duration, soaking time, parboiling temperature, and drying temperature for*Ofada*milled rice processing for present and prospective investors that would have relied on "trial and error" method in processing *Ofada* rice for various end uses.
- Information on the optimum processing conditions of Ofada rice into flour for the production of ready-to-eat flake as an alternative mean of utilization was provided.
- Mathematical modelling of effect of physical, chemical, cooking, and pasting properties of *Ofada rice*and flakes as affected by storage and processing parameters.
- Identification of volatile compounds responsible for aromatic quality of*Ofada* rice.
- Technical data on moisture adsorption characteristics of ready-to-eat *Ofada* flakes and best model for moisture stability prediction were supplied.

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APPENDIX 1

SENSORY EVALUATION OF FLAKES

Name:

Date:

You are provided with three coded samples of ready to eat rice flakes. Kindly evaluate the samples with the number category scale.

Sample codes	Colour	Aroma	Crispiness	Taste	General acceptability
601	....	....	....	....	....
659	....	....	....	....	....
723	....	....	....	....	....

Category scale

Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

APPENDIX 2

Computer print out for sensory analysis

GET FILE='C:\Users\Lukman\Documents\flake sensory.sav'. ONEWAY Aroma Taste Crispiness Acceptability Colour BY Judges /MISSING ANALYSIS /POSTHOC=TUKEY DUNCAN LSD WALLER(100) ALPHA(0.05).

Oneway

Notes

Output Created		22-Feb-2014 10:41:30
Comments		
Input	Data	C:\Users\Lukman\Documents\flake sensory.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	30
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on cases with no missing data for any variable in the analysis.

Syntax		ONEWAY Aroma Taste Crispiness Acceptability Colour BY Judges /MISSING ANALYSIS /POSTHOC=TUKEY DUNCAN LSD WALLER(100) ALPHA(0.05).
Resources	Processor Time	0:00:00.234
	Elapsed Time	0:00:00.234

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Aroma	Between Groups	.867	2	.433	.416	.664
	Within Groups	28.100	27	1.041		
	Total	28.967	29			
Taste	Between Groups	.867	2	.433	.557	.579
	Within Groups	21.000	27	.778		
	Total	21.867	29			
Crispiness	Between Groups	.467	2	.233	.212	.810
	Within Groups	29.700	27	1.100		
	Total	30.167	29			
Acceptability	Between Groups	4.467	2	2.233	2.885	.073
	Within Groups	20.900	27	.774		
	Total	25.367	29			
Colour	Between Groups	12.067	2	6.033	8.227	.002
	Within Groups	19.800	27	.733		
	Total	31.867	29			

Post Hoc Tests

Multiple Comparisons

Dependent Variable		(I) Judges	(J) Judges	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Aroma	Tukey HSD	601	659	.300	.456	.790	-.83	1.43
			723	.400	.456	.659	-.73	1.53
		659	601	-.300	.456	.790	-1.43	.83
			723	.100	.456	.974	-1.03	1.23
		723	601	-.400	.456	.659	-1.53	.73
			659	-.100	.456	.974	-1.23	1.03
	LSD	601	659	.300	.456	.516	-.64	1.24
			723	.400	.456	.388	-.54	1.34
		659	601	-.300	.456	.516	-1.24	.64
			723	.100	.456	.828	-.84	1.04
		723	601	-.400	.456	.388	-1.34	.54
			659	-.100	.456	.828	-1.04	.84
Taste	Tukey HSD	601	659	.400	.394	.574	-.58	1.38

			723	.300	.394	.730	-.68	1.28
		659	601	-.400	.394	.574	-1.38	.58
			723	-.100	.394	.965	-1.08	.88
		723	601	-.300	.394	.730	-1.28	.68
			659	.100	.394	.965	-.88	1.08
	LSD	601	659	.400	.394	.319	-.41	1.21
			723	.300	.394	.453	-.51	1.11
		659	601	-.400	.394	.319	-1.21	.41
			723	-.100	.394	.802	-.91	.71
		723	601	-.300	.394	.453	-1.11	.51
			659	.100	.394	.802	-.71	.91
Crispiness	Tukey HSD	601	659	.300	.469	.800	-.86	1.46
			723	.100	.469	.975	-1.06	1.26
		659	601	-.300	.469	.800	-1.46	.86
			723	-.200	.469	.905	-1.36	.96
		723	601	-.100	.469	.975	-1.26	1.06
			659	.200	.469	.905	-.96	1.36

	LSD	601	659	.300	.469	.528	-.66	1.26
			723	.100	.469	.833	-.86	1.06
		659	601	-.300	.469	.528	-1.26	.66
			723	-.200	.469	.673	-1.16	.76
		723	601	-.100	.469	.833	-1.06	.86
			659	.200	.469	.673	-.76	1.16
Acceptability	Tukey HSD	601	659	-.900	.393	.075	-1.88	.08
			723	-.200	.393	.868	-1.18	.78
		659	601	.900	.393	.075	-.08	1.88
			723	.700	.393	.196	-.28	1.68
		723	601	.200	.393	.868	-.78	1.18
			659	-.700	.393	.196	-1.68	.28
	LSD	601	659	-.900*	.393	.030	-1.71	-.09
			723	-.200	.393	.615	-1.01	.61
		659	601	.900*	.393	.030	.09	1.71
			723	.700	.393	.086	-.11	1.51
		723	601	.200	.393	.615	-.61	1.01

			659	-.700	.393	.086	-1.51	.11
Colour	Tukey HSD	601	659	-.400	.383	.556	-1.35	.55
			723	-1.500*	.383	.002	-2.45	-.55
		659	601	.400	.383	.556	-.55	1.35
			723	-1.100*	.383	.021	-2.05	-.15
		723	601	1.500*	.383	.002	.55	2.45
			659	1.100*	.383	.021	.15	2.05
	LSD	601	659	-.400	.383	.306	-1.19	.39
			723	-1.500*	.383	.001	-2.29	-.71
		659	601	.400	.383	.306	-.39	1.19
			723	-1.100*	.383	.008	-1.89	-.31
		723	601	1.500*	.383	.001	.71	2.29
			659	1.100*	.383	.008	.31	1.89

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Aroma

	Judges	N	Subset for alpha = 0.05 1
Tukey HSD[a]	723	10	6.80
	659	10	6.90
	601	10	7.20
	Sig.		.659
Duncan[a]	723	10	6.80
	659	10	6.90
	601	10	7.20
	Sig.		.416

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Taste

	Judges	N	Subset for alpha = 0.05 1
Tukey HSD[a]	659	10	7.10
	723	10	7.20
	601	10	7.50
	Sig.		.574
Duncan[a]	659	10	7.10
	723	10	7.20
	601	10	7.50
	Sig.		.348

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Crispiness

	Judges	N	Subset for alpha = 0.05
			1
Tukey HSD[a]	659	10	6.00
	723	10	6.20
	601	10	6.30
	Sig.		.800
Duncan[a]	659	10	6.00
	723	10	6.20
	601	10	6.30
	Sig.		.552

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Acceptability

	Judges	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	601	10	6.40	
	723	10	6.60	
	659	10	7.30	
	Sig.		.075	
Duncan[a]	601	10	6.40	
	723	10	6.60	6.60
	659	10		7.30
	Sig.		.615	.086

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Colour

	Judges	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	601	10	6.30	
	659	10	6.70	
	723	10		7.80
	Sig.		.556	1.000
Duncan[a]	601	10	6.30	
	659	10	6.70	
	723	10		7.80
	Sig.		.306	1.000
Waller-Duncan[a,,b]	601	10	6.30	
	659	10	6.70	
	723	10		7.80

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

b. Type 1/Type 2 Error Seriousness Ratio = 100.

PLATES

A11.1. Ofada Rice Products

S-5days, P-120^{o}C, D-70^{o}C, T-1 month

S-5 days, P-80C, D-30C,T-1 month

S-1 day, P-80^{o}C, D-70^{o}C, T-1month

S-5days, P-80^{o}C, D-30^{o}C, T- 9 months

S-1 day, P-80^{o}C, D-30^{o}C, T-5 months

S-3 days, P-80^{o}C, D-50^{o}C, T-5 months

S-1 day, P-80^{o}C, D-70^{o}C, T- 1 month

S-5 days, P-120^{o}C, D-30^{o}C, T-5 months

S-5 days, P-120°C, D-70°C, T-9 months

S-3 days, P-100°C, D-50°C, T- 9 months

S-3, P-120°C, 50°C, T-5 months

S-1 day, P-120°C, D-50°C, 9 months

S-3, P-120°C, D-30°C, T-9 months

S-5 days, P-120°C, D-70°C, T-1 month

S-5 days, P-100°C, 50°C, T-5 months

S-1 day, P-100°C, D-50°C, T-5 months

S-1 day, P-120°C, D- 70°C, T-5 months

S-3 days, P-100°C, D-50°C, T-5 months


S-5 days, P-80^{o}C, D-30^{o}C, T-1 month


S-5 days, P-80^{o}C, D-70^{o}C, T-5 months


S-1 day, P- 120^{o}C, D- 30^{o}C, T- 1 month


S-1 day, P-80^{o}C, D-70C, T- 9 months


S- 1 day, P-100^{o}C, D- 30^{o}C, T-9 months


S-5 days, P-80^{o}C, D-30^{o}C, T- 9 months

A11.2. Optimized Ofada rice

S-1 day, P- 120°C, D-30°C, T- 1 month

A11.3. Rice flakes

S-5 days, P-120°C, D-70°C, T-1 Month

S-5days, P-120°C, D-30°C, T-5 months

S-1 day, P-80°C, D-70°C, T-1 month

S-1 day, P-80°C, D-70°C,T-1 month

S-1 day, P-80°C, D-30°C, T-5 months

S-5 days, P-120°C, D-70°C, T-9 months

S-5 days, P-80°C, D-30°C, T-1 month

S-3 days, P-120°C, D-50°C, T-5 months

S-5 days, P-80°C, D-30°C, T-9 months

S-3 days, P-120°C, D-30°C, T-9 months

S-1 day, P-120°C, D-50°C, T-9 months

S-5 days, P-100^{o}C,D-50^{o}C, T-5 months

S-1 day, P-120^{o}C, D-70^{o}C, T- 5 months

S-3 days, P- 100^{o}C , D-50^{o}C, T- 9 months

S-5 days, P-120^{o}C, D-70^{o}C, T-1 month

S-1 day, P-100^{o}C, D-50^{o}C, T-5 months

S-3 days, P-100^{o}C, D- 50^{o}C, 5 months

S-5 days, P- 80^{o}C, D- 30^{o}C, T- 1 month

S-1 day, P-120^{o}C, D- 30^{o}C, T- 1 month

S-1 day, P-100^{o}C, D- 30^{o}C, T- 9 months

S- 5 days, P-80^{o}C, D-70^{o}C, T-5 months

S-1 day, P- 80C, D- 70C, T- 9 months

S-5 days, P- 80^{o}C, D-30^{o}C, T- 9 months

S-1, P-120C, D-30C, T- 1 month

A.11.4. Optimized ofada flake products

S-4.70 days, P-106.16°C, D-30°C, T-9 months

S-1.94 days, P-114.80°C, D-70°C, T-9 months

S-1.91 days, P-114.54°C, D-70°C, T-8.93 months